# 3.0 ENVIRONMENTAL SETTING

This section describes the current and historical physical characteristics and human uses of the Portland Harbor Superfund Site (Site). Physical characteristics of the Site include meteorology, regional geology and hydrogeology, surface water hydrology, the physical system (which includes bathymetry, sediment characteristics, and hydrodynamics and sediment transport), habitat, and surface features. Human characteristics of the Site that are discussed here include historical and current land and river use, the municipal sewer system, and human access and use. In addition to providing context to the RI sampling and analysis, the factors presented in this section are considered in the refinement of the study area-wide CSM, which is presented in Section 10.

Section 3.1 focuses primarily on the physical setting within the study area (RM 1.9 to 11.8). However, the physical features of the Willamette River from Willamette Falls (RM 26) to the Columbia River (RM 0), as well as the upstream portion of Multnomah Channel, are discussed as needed to place the study area's physical characteristics into a regional context.

The Willamette River basin has a drainage area of 11,500 square miles and is bordered by foothills and mountains of the Cascade and Coast ranges up to 10,000 ft high to the south, east, and west (Trimble 1963). The main channel of the Willamette forms in the southern portion of the valley near Eugene, at the convergence of the Middle and Coast forks. It flows through the broad and fertile Willamette Valley region and at Oregon City flows over the Willamette Falls and passes through Portland before joining the Columbia River (Map 3.1-1).

The Willamette flows predominantly from the south to the north and has a total length of about 309 miles. It is the 19$^{th}$ largest river in the contiguous United States in terms of discharge. The portion of the river from Willamette Falls to the Columbia River is considered the lower Willamette River (see Map 1.0-1). Multnomah Channel is a distributary channel of the lower Willamette River that begins at RM 3.1 and flows northwest approximately 21 miles to its confluence with the Columbia River.

The upstream reaches of the Willamette River above Willamette Falls constitute a meandering and, in some cases, braided river channel. Upstream flooding is largely controlled by 13 major tributary reservoirs (Uhrich and Wentz 1999). In the lower Willamette River, especially in the vicinity of Portland Harbor, the channel banks have been stabilized in several areas by the placement of riprap, and construction of seawalls, bulkheads, etc. These measures have created a much more stable channel in the lower Willamette River.

The portion of the river where the federal navigation channel is maintained at –40 ft CRD (see Section 3.1.4.1) defines Portland Harbor and extends upstream from the Columbia River (RM 0) to the Broadway Bridge (RM 11.7; Map 1.0-1). From 1973 through 2007, average annual mean flow in the Willamette River was approximately 33,800 cfs at the Morrison Bridge (near RM 12.8) in Portland.[1]

## 3.1 PHYSICAL ENVIRONMENT

### 3.1.1 Meteorology

Located about 65 miles inland from the Pacific Ocean, the city of Portland and Portland Harbor are situated near the confluence of the Willamette and Columbia rivers. This area lies approximately 20 ft above sea level and is about midway between the Coast Range to the west and the Cascades Range to the east. The climate of Portland is usually described as temperate or oceanic, with mild, damp winters and relatively dry, warm summers. The Coast Range provides limited protection from Pacific Ocean storms while the steep slope of the Cascades Range impedes moisture-laden westerly winds, resulting in moderate rainfall in the area, especially during the winter months (NOAA 2010).

Precipitation falls primarily as rain, with nearly 90 percent occurring between mid-October and mid-May. Rainfall varies across the metropolitan area, with the West Hills (located to the west of the study area) receiving nearly 60 inches of rain per year while the Portland International Airport (located to the east of the study area) only receives about 36 inches. Forest Park, which is located in the West Hills, drains to the study area. Measurable snow accumulations are rarely more than 2 inches, occurring most frequently at elevations over 500 ft (including the West Hills) or along Portland's eastern boundary near the Columbia River Gorge at Troutdale (NOAA 2010). The city has experienced some major snow and ice storms caused by cold air outflow from the gorge. A storm in 1893 resulted in approximately 60 inches of snow accumulation (NOAA 2010).

Winds are from the north and west during the late spring and summer dry season and from the east and south during the fall and winter rainy season. Annual monthly wind speeds average 8.0 mph at the Portland airport (NOAA 2011). Average temperatures range from a low of 45°F (7°C) in the winter months to a high of the middle 90s (~35°C) in the late summer (NOAA 2000). The lowest temperature ever recorded in Portland was −3°F (−19°C), which occurred on February 2, 1950. The highest temperature ever recorded was 107°F (42°C), on July 30, 1965 and again on August 8 and 10, 1981 (NOAA 2011).

### 3.1.2 Geology

#### 3.1.2.1 Geologic Setting

The study area is located along the southwestern edge of a large geologic structure known as the Portland Basin. The Portland Basin is a bowl-like structure that is 40 miles long and 20 miles wide and bounded by folded and faulted uplands. These

[1] Data obtained from the USGS Water Resources web site (http://waterdata.usgs.gov/or/nwis/sw).

northwest-trending structural zones are interpreted as dextral wrench faults that delineate the Portland pull-apart basin (Beeson et al. 1985; Yelen and Patton 1991). The Tualatin Mountains (Portland West Hills) form a ridge that runs parallel to the Willamette River to the west, from the Multnomah Channel to the City of Portland. The mountains define the western edge of the Portland Basin; groundwater and creeks and channels along the east face of the mountains flow downward to the Willamette River.

The basin has been filled with up to 1,400 ft of alluvial and glacio-fluvial flood deposits since the middle Miocene (approximately 12 million years ago). These sediments overlie older (Eocene and Miocene) rocks including the Columbia River Basalt Group (CRBG), Waverly Heights basalt, and older marine sediments. The older rocks are exposed where uplifting has occurred (e.g., RM 7 west side in the Doane Lake area) on the margins of the basin, including adjacent to the study area.

Because the study area is located at the edge of the basin, both the older rocks and overlying sediments are present near the surface and play a significant role in defining interactions between groundwater and the river. The geologic units found in the vicinity of the study area are illustrated in Figure 3.1-1 and briefly described below, from youngest to oldest (Beeson et al. 1991; Swanson et al. 1993):

#### 3.1.2.1.1 Recent Anthropomorphic Fill

Anthropomorphic fill blankets much of the lowland area next to the river and is predominantly dredged river sediment, including fine sand and silty sand. Hydraulic dredge fill was used to fill portions of the flood plain, such as Doane Lake, Guild's Lake, Kittridge Lake, Mocks Bottom, Rivergate, and a number of sloughs and low-lying areas. The fill also was used to connect Swan Island to the east shore of the Willamette River and to elevate or extend the bank along significant lengths of both sides of the riverfront by filling behind artificial and natural silt and clay flood levee dike structures. Rocks, gravel, sand, and silt also were used to fill low-lying upland and bank areas. The thickness of this unit ranges from 0 to 20 or more feet. The permeability of this unit, where composed of clean dredge fill sand, is higher than the natural fine-grained alluvium. The presence of silt fill or a silty matrix in the sand fill generally reduces the permeability of the unit significantly.

#### 3.1.2.1.2 Fine-grained Pleistocene Flood Deposits and Recent Alluvium (Undifferentiated)

This unit includes fine-grained facies of the Pleistocene Flood Deposits, as well as recent alluvium deposited by the present Willamette River. This unit generally consists of silt, clay, silty sand, and fine-to-medium sand that borders and underlies the present floodplain of the river (Beeson et al. 1991). The lower portions of this unit and where it forms the large bluffs bordering the east side of the river likely consist of the fine-grained facies of the flood deposits, whereas the upper portions near the river are likely more recent alluvium. The upper fine-grained portion of the unit has likely been reworked and deposited by the present Willamette River. The sands of this unit may be indistinguishable from overlying dredge fill in some places (Landau 2002a). The thickness of this unit ranges from 20 to over 100 ft. The permeability of the clay, silt, and silty sand of this unit is generally relatively low, whereas the portions of the unit consisting of clean sands may have a relatively higher permeability. This unit forms part of the Unconsolidated Sedimentary Aquifer regional hydrostratigraphic unit proposed by Swanson et al. (1993).

##### 3.1.2.1.3 Coarse-grained Pleistocene Flood Deposits (Gravels)

This unit includes fluvial deposits from the Pleistocene Missoula floods. The deposits fill deep channels that were incised into the Troutdale Formation and CRBG during the floods. The unit consists of uncemented sand, gravel, and cobbles with boulders in places. This unit is generally between 10 and 200 ft thick in the vicinity of the study area and underlies fine-grained flood deposits and recent alluvium under much of the study area. The Willamette River subsequently incised the flood deposits in places. The rise in sea level from the end of the Pleistocene to the present resulted in the filling of the incised channel by finer-grained flood and recent alluvial facies to form the current floodplain channel of the river.

##### 3.1.2.1.4 Upper Troutdale Formation

The upper Troutdale Formation in the vicinity of the lower Willamette River includes cemented and uncemented alluvial sand, gravel, and cobbles deposited by the ancestral Willamette and Columbia rivers. The Troutdale Formation comprises the Troutdale Gravel Aquifer hydrostratigraphic unit. This unit is present in some places on the west side of the study area to thicknesses of 100 ft and is present along the entire length of the east side of the study area at thicknesses of up to 200 ft (Swanson et al. 1993).

##### 3.1.2.1.5 Lower Troutdale Formation/Sandy River Mudstone

The Sandy River Mudstone (SRM) is a fine-grained equivalent of the lower Troutdale Formation (channel facies) that overlies the CRBG in the center of the basin and at the margins of the basin away from the axis of the Columbia River. The lower Troutdale Formation/SRM is present in places under the lower Willamette River (Swanson et al. 1993) and borders the Portland Hills, but is not considered a significant hydrogeologic unit within the study area. The lower Troutdale Formation/SRM consists mostly of silt and clay with lenses of sand and gravel and tends toward fine-grained (low permeability) textures at the basin margins (Swanson et al. 1993).

##### 3.1.2.1.6 Columbia River Basalt Group

The CRBG consists of a thick sequence of Miocene basalt flows dating from between 17 and 6 million years ago (mya), but the CRBG flows that underlie much of the Portland Basin entered the area between 16.5 mya and 12 mya. Basalt flows of the CRBG were folded and faulted during the uplift of the Tualatin Mountains, concurrent with eruption and emplacement of younger flows present in the Portland Basin (Beeson et al. 1991). The CRBG is present at the surface or at relatively shallow depths along the west side of the study area and may be in direct contact with the river in places. The top of the unit drops off below ground surface (bgs) over a relatively short distance and is 400 or more feet bgs on the east side of the study area. The thickness of the CRBG in the vicinity of the study area is estimated to be approximately 600 ft (Beeson et al. 1991).

#### 3.1.2.2 Tectonic Setting

Portland Harbor's tectonic setting is an important element of the regional geology. The regional sources of seismicity affecting the Portland Metropolitan area are associated with three separate fault mechanisms. These include "mega-thrust" subduction earthquakes (moment magnitude [Mw] 8 to 9) and relatively deeper, Benioff-zone, intraplate events (Mw 6.5 to 7.3) both associated with the Cascadia Subduction Zone (CSZ), as well as the relatively shallow crustal zone earthquakes (Mw 5.0 to 7.0). Geotechnical analyses for seismic hazards associated with liquefaction and earthquake-induced slope deformation require that the specific earthquake sources be recognized so that effects of ground motion attenuation, duration, and frequency content of these hazards can be assessed. Descriptions of these potential earthquake sources are presented as follows.

##### 3.1.2.2.1 Cascadia Subduction Zone

The CSZ extends from Northern California to British Columbia and the seismogenic portion of the CSZ is largely located offshore at the latitude of Portland. Within this zone, the oceanic Juan De Fuca Plate is being subducted beneath the continental North American Plate to the east. The interface between the two plates is dipping to the east, and, therefore, becomes deeper toward Portland. At the easternmost portion of the interface zone that is thought to be capable of generating strong ground motions, the interface between these two plates is located at a depth of approximately 20 to 25 km. Quantifying the seismicity and hazard posed by the CSZ is subject to several uncertainties, including the size of the maximum credible earthquake as described by the moment magnitude of the event, the rate of seismicity associated with the CSZ, and the nature of the ground motions associated with CSZ earthquakes. Geologic evidence of previous CSZ earthquakes has been observed within coastal marshes along the Oregon coast and in offshore landslide deposits (turbidites). These paleoseismic data have been used to infer the size of prehistoric earthquakes as well as their rate of recurrence. These geologic investigations indicate that large (Mw > 8) subduction zone earthquakes along Cascadia occur at intervals on the order of 300 to 500 years, well within the period of interest for this project. The most recent mega-thrust earthquake is estimated to have occurred approximately 300 years ago.

Based on the most current Probabilistic Seismic Hazard Analyses performed by the USGS National Seismic Hazard Mapping Program (Petersen et al. 2011), the closest distance from the Site to the portion of the CSZ that is thought to be capable of generating significant ground motions is approximately 95 to 100 km. This fault location is consistent with that specified by agencies such as the Oregon Department of Transportation (ODOT), USACE, and U.S. Bureau of Reclamation, and accepted by regulatory agencies such as the Federal Energy Regulatory Commission.

##### 3.1.2.2.2 Benioff Zone

The Benioff zone encompasses the portion of the subducting Juan De Fuca Plate located at a depth of approximately 30 to 50 km below western Oregon. Very low levels of seismicity have been observed within the intraplate zone in Oregon. However, much higher levels of seismicity within this zone have been recorded in Washington and California. Several reasons for this seismic quiescence were suggested by Geomatrix (1995) and these include changes in the direction of subduction between Oregon and British Columbia as well as the effects of volcanic activity along the Cascade Range. Historical activity associated with the intraplate zone includes the 1949 Olympia Mw 7.1, 1965 Puget Sound Mw 6.5, and 2001 Nisqually Mw 6.8 earthquakes. The regional Probabilistic Seismic Hazard Analysis prepared for the USGS (Petersen et al. 2011) indicates that the Benioff zone earthquakes significantly contribute to the seismic hazard at the return period associated with the contingency level event (i.e., 475 years).

##### 3.1.2.2.3 North American Plate

The third source of seismicity that can result in significant ground shaking within the greater Portland area is near-surface, crustal earthquakes occurring within the North American Plate. The historical seismicity of moderate-sized crustal earthquakes in western Oregon is higher than the seismicity associated with the CSZ and the intraplate zone. The 1993 Scotts Mills (Mw 5.6) and Klamath Falls (Mw 6.0) earthquakes are examples of relatively shallow (approximately 15 km) crustal earthquakes. The characterization of the local crustal earthquake sources includes known faults thought to be active in the Portland region, and consideration of possible seismicity that may occur in the region along unmapped sources. The crustal earthquakes that occur along currently unmapped faults in the region have been referred to in seismic hazard investigations as “randomly occurring” earthquakes, “aerial sources,” or “gridded seismicity.”

### 3.1.3 Hydrogeology

The current understanding of the generalized hydrogeology of the study area is presented in this section. The detailed hydrogeology of the upland areas on both sides of the river varies by location. This generalized discussion is intended to describe the important basic hydrogeologic units and their properties and groundwater flow within the study area and is not representative of any one particular location. An upland groundwater data review that summarizes hydrogeologic information and groundwater quality data from specific upland sites in the vicinity of the study area has been completed by the LWG (GSI 2003b).

#### 3.1.3.1 Hydrogeologic Units

The geologic units described above can be grouped into study area-wide hydrogeologic units on the basis of having generally similar hydrogeologic characteristics. Important hydrogeologic characteristics include the position of the water table relative to each hydrogeologic unit, the physical relationship between each hydrogeologic unit and the river, and physical characteristics of each hydrogeologic unit, such as permeability, heterogeneity, and anisotropy.

These hydrogeological units are described from uppermost to lowermost in the following sections and presented in Figure 3.1-2.

#### 3.1.3.1.1 Fill, Fine-grained Facies of Flood Deposits, and Recent Alluvium

The fill, fine-grained facies of flood deposits, and recent alluvium (FFA) unit is composed of the fill, the combined fine-grained facies of the Pleistocene flood deposits, and the recent alluvium geologic units described by Beeson et al. (1991) and in Section 3.1.2. These geologic units were grouped together on the basis of each unit's shared textures and intrinsic heterogeneity, proximity to the river and to each other, and importance with regard to the occurrence of upland groundwater and interactions with the river.

This unit, which encompasses a broad range of soil textures and hydraulic characteristics, blankets much of the lowland area next to the river and includes much of the material abutting the river. The unit also consists of the fine sand and silty sand dredge fill overlying recent and Pleistocene silt and clay overbank sediments, which are interbedded with lenses and layers of fine to coarse sand. As discussed in Section 3.1.2.1.1, the dredge fill was placed behind low-permeability, artificial and natural flood levee dike structures in some locations. The thickness of this unit can be up to 150 ft, but it typically ranges between 30 and 100 ft.

The FFA hydrogeologic unit is the primary unit of importance in defining the interactions between upland groundwater and the river because of the following characteristics of the unit:

- The unit forms most of the river channel within the study area as well as the surrounding upland areas and, therefore, controls groundwater interactions with the river
- Most contaminated groundwater plumes present in the upland areas occur within strata of this unit.

The distribution of textures and thus groundwater flow properties of the unit vary both vertically and horizontally by location along the study area. Silt, clay, and silty sand are present adjacent to the river at a majority of locations where the unit is observed near low river stage levels. Boring logs at sites north of RM 4 on the east side of the river indicate that a greater portion of the unit north of RM 4 and at depths below low river stage levels consists of sand layers. This is generally true for most of the shallower areas within historical Portland Harbor flood plain. Comparison of hydraulic conductivity values for different textures within the FFA unit listed below illustrates the importance of the channel sand lenses and layers in focusing groundwater fluxes to the river at any particular location where present within this unit:

- Silt/clay: 0.005 to 2 ft per day (0.0000018 to 0.0007 cm/s)

- Silty sand: 0.1 to 2 ft per day (0.000035 to 0.0007 cm/s)
- Sand: 0.5 to 30 ft per day (0.00018 to 0.011 cm/s).

The typical measured hydraulic conductivities in the silt/clay facies of the FFA indicate that groundwater fluxes from these sediments within the study area are generally low. Identification of seeps present in silt/clay during the seep reconnaissance survey (GSI 2003a) is consistent with this conclusion. Conversely, groundwater fluxes from the uplands to the river within the FFA are expected to be greater in those areas where more permeable sand zones are present, such as on the east side of the river.

##### 3.1.3.1.2 Coarse-grained Flood Deposits and Upper Troutdale Formation

The coarse-grained flood deposits and Upper Troutdale Formation (CGF) unit combines the unconsolidated coarse-facies flood deposits, including sands, gravels and cobbles, with the underlying uncemented and cemented gravels and cobbles of the upper Troutdale Formation. The flood gravels that compose the upper portion of this unit typically occupy scour channel surfaces on older units (e.g., the CRBG). Anthropomorphic fill, silt, clay, and sand of the flood deposits, and alluvium mostly cover the CGF, except in places on the highland bluffs on the east side of the river where the unit may be exposed.

The CGF unit is adjacent to and underlies much of the study area to thicknesses exceeding 200 ft. The overall thickness of the unit is more typically in the range of 100 ft. However, the unit is missing in places, including on the west side of the river towards the south end of the study area and directly under the river at RM 7. The top of the CGF unit is present at elevations of 0 ft to over –100 ft mean sea level (MSL). The unit is present at relatively shallow depths adjacent to the west side of the river in the vicinity of the Doane Lake area and may be in contact with river sediments. The hydraulic conductivity of this unit measured in the vicinity of the Doane Lake area ranges from 3 ft per day (0.0011 cm/s) to greater than 40 ft per day (0.014 cm/s) (AMEC 2001).

Because this unit has a relatively higher hydraulic conductivity than the overlying FFA unit, groundwater may flow more readily through this unit to deeper units where downward gradients are present and where the unit is present adjacent to the river, allowing deeper groundwater to more readily discharge to the river. Higher fluxes to the river within the CGF unit may increase downward gradients and thus increase groundwater and contaminant plume movement in the FFA unit. The effect of the CGF unit on groundwater flow in the FFA is a factor in the selection of characterization methods. Locations where the CGF unit may exert a stronger influence on deeper groundwater flow to the river, and thus vertical gradients in the FFA, include the Doane Lake area (RM 6–7W), the southern edge of the study area (RM 11), and on the east side of the river in the vicinity of the International Terminal (RM 4E).

#### 3.1.3.1.3 Lower Troutdale Formation/Sandy River Mudstone

This hydrogeologic unit is present in some places under the west side of the study area and is present under the entire length of the east side of the study area. The unit is predominantly silt and clay where explored in the vicinity of the study area, and thus the permeability of the unit is low. Where present, the unit overlies the CRBG below depths of –100 to –150 ft MSL and tends to pinch out on the west side and towards the southern end of the study area where the CRBG is present at shallower depths. The unit typically is separated from the river by at least 100 to 200 ft of alluvium and deposits of the upper Troutdale Formation. Based on the hydrogeologic characteristics of this unit and the depth relative to the river, it is not considered to contribute significantly to surface water/groundwater interactions within the study area.

#### 3.1.3.1.4 Columbia River Basalt Group

The CRBG consists of a concordant sequence of basalt lava flows. Groundwater flow in the CRBG is focused along the higher permeability interflow zones and in some areas of fracture-enhanced permeability (e.g., faults). Hydraulic conductivities measured in individual basalt interflow zones in the vicinity of the study area range from 1.5 to 10.9 ft per day (0.00053 to 0.0038 cm/s) (AMEC 2001). Hydraulic conductivities measured in CRBG basalt flow interiors at Hanford, Washington, range from $1\times10^{-4}$ to $1\times10^{-7}$ ft per day ($3.5\times10^{-8}$ to $2.5\times10^{-13}$ cm/s) (Strait and Mercer 1986), illustrating that the basalt interflow zones (flow top and bottom collectively) are the primary groundwater flow pathways in the CRBG.

The CRBG is present at relatively shallow depths along portions of the west side of the study area and may be in direct contact with the river in places. The top of the unit is irregular on the west side of the study area with channels from scouring by flood events and the ancestral Willamette River. The top of the unit on the west side of the study area is between elevation 0 ft and –50 ft MSL north of RM 9, except for an ancestral channel in the vicinity of Doane Lake (Figure 3.1-1). The top of the CRBG slopes down to an elevation of –250 ft MSL or more across the river on the east side of the study area. The relief of the unit across the study area appears to be due to structural downwarping towards the center of the basin, and may be accentuated by normal faulting postulated along both sides of the study area (Beeson et al. 1991; Beeson 2003, pers. comm.). The overall significance of the CRBG with regard to groundwater/surface water interactions within the study area is not well characterized; however, the CRBG is considered to be most relevant to groundwater interactions with the river on the west side of the river downstream of about RM 9 because of its proximity to the river.

### 3.1.3.2 Groundwater Flow

The general groundwater flow systems of interest recognized along the study area are a shallow (shallow FFA), an intermediate (deep FFA), and a deep (CGF and CRBG) system. A deeper, regional flow system also is present, which includes the CRBG, where it is deep below the river (on the east side of the river), and lower Troutdale Formation/SRM. This deeper, regional flow system is not considered to be important in understanding the interactions between upland groundwater and the river that are relevant to this RI. The deeper, regional flow system may be relevant to contaminated groundwater or product from upland sources that may be posing a threat to such a system.

At a local level, these divisions between flow systems are likely indistinct in places along the study area. Additionally, some investigations have identified further flow system refinements or divisions based on the local hydrogeology. However, the general flow systems described above appear to apply for the majority of the study area and provide a general model from which variations can be evaluated on a local scale. Figure 3.1-3 presents the generalized conceptual picture of groundwater flow through these flow systems. This figure supports the following discussions of groundwater flow systems.

The Willamette River is the focus of discharge for the three flow systems of interest to the RI, including where the CRBG is present near the surface on the west side of the river. The shallow flow system is the primary focus of most upland groundwater investigations, and is the focus of this RI because most of the upland groundwater affected by contaminants of interest is present within this system, and this system discharges to the shallow and nearshore areas where exposure to human and ecological receptors is most likely. The potential for impact to the deeper system is relatively low, except where there may be a large source of dense, nonaqueous-phase liquid (DNAPL) that has the potential to migrate to the FFA and/or upper portion of the basalt. Impact to sediments from the shallow and intermediate flow systems are the focus of this RI, except at locations where the CGF and CRBG appear to be impacted by chemical constituents and are connected to the river.

#### 3.1.3.2.1 Shallow Flow System

The shallow, unconfined, groundwater flow system along the margins of the study area consists mostly of fill and alluvial silt and clay deposits and some medium- to coarse-grained channel sand of the shallow FFA that blankets the lowlands next to the river, as shown in the generalized conceptual image on Figure 3.1-3. At many locations, the shallow flow system is hosted within the lower portion of fine dredge-fill sand and underlying silty sand and silt. The shallow system is recharged by direct precipitation and infiltration, infiltration from the hills on the west side of the study area, and exchange with several surface water bodies along the study area (e.g., Doane Lake). Groundwater in this system is unconfined. Groundwater level data in the upland areas indicate that there is a downward gradient toward deeper units from the shallow system. Groundwater levels and fluxes in the shallow system are affected by seasonal river stage changes, as well as by diurnal tidal influences. The degree of tidal influence decreases with increasing distance from the river and shallower groundwater depths. Groundwater gradients within the shallow system are generally steep immediately adjacent to the river and flatten out away from the river bank. The shallow flow system discharges to the river either above the river surface as surface seeps, or below the river surface as subsurface discharge, generally in nearshore areas. Because of tidal and seasonal river stage fluctuations, a given groundwater discharge may express above or below the river surface at different times.

The permeability of the FFA materials is variable within the shallow flow system, but generally is relatively low. The presence of low-permeability features, such as silt and clay dikes constructed to retain hydraulically emplaced dredge fill, cutoff walls, and retaining walls, may act to impede groundwater flow locally in the shallow system, resulting in higher groundwater levels and steep shallow groundwater gradients near the shore. The presence of preferential pathways (human-made and natural) in the shallow FFA can be a significant, albeit localized, influence on the discharge of groundwater to the river.

Light, nonaqueous-phase liquid spills are present only within the shallow flow system. Dissolved chemicals associated with upland releases are present in the shallow flow system. Dissolved plumes may be affected by vertical hydraulic gradients, which may cause vertical migration of the dissolved constituents. The shallow system also appears to influence the effect of DNAPL releases by retaining a portion of the released volume through spreading and retention in or along less permeable sediments. These stratigraphic controls can limit the depth of downward migration of DNAPL.

##### 3.1.3.2.2 Intermediate Flow System

The intermediate flow system occurs within thicker sequences of the fine-grained alluvial sediments of the FFA. Groundwater in the intermediate system generally discharges to the Willamette River below the river surface to deeper portions of the river (Figure 3.1-3), with discharge focused at the locations where more permeable strata (typically sand) may intersect the river. Horizontal hydraulic gradients within the intermediate flow system tend to be flatter near the river than observed in the shallow system, and thus high river stages and tidal changes may exert a greater influence on fluxes from the intermediate system to the river by further flattening or perhaps reversing the gradient locally.

The intermediate flow system is particularly relevant for groundwater transport of chemicals to the river where DNAPL is present or where chemical densities, preferential pathways, or downward gradients could potentially allow dissolved chemical constituents to penetrate into the deeper units. The intermediate flow system is the most likely mechanism that would allow for groundwater discharge into the sediments present in the deeper portions of the Willamette River. However, most groundwater chemical plumes identified in the upland areas of the study area do not occur within the intermediate flow system.

##### 3.1.3.2.3 Deep Flow System

The deep flow system occurs within the CGF and basalt interflow zones of the CRBG, where the CRBG is present near the surface on the west side of the river. Downstream of about RM 9 on the west side of the river, residual basalt gravels immediately overlying the CBRG have been identified as important hydrogeologic features and potential conduits for groundwater contaminant transport. Groundwater in the deep system discharges to the Willamette River only in deeper portions of the river, with discharges focused at the locations where the gravels and/or basalt interflow zones are near or intersect the river sediments (Figure 3.1-3).

The CRBG does not play a role in the deep flow system on the east side of the river, because it occurs at substantially greater depth due to structural downwarping and associated normal faulting. The flow system becomes strongly affected by the Columbia River on the east side of the study area with increasing distance from the Willamette River. Deep groundwater flow from the base of Tualatin Hills toward the east side of the river occurs in the CGF, which is generally highly transmissive; however, gradients may be relatively low. Seasonal gradient reversals are known to occur during periods of high river stages. Where near the river, the connection, and thus response, to river stage changes is expected to be great.

The deep flow system is not anticipated to play a significant role in groundwater contaminant transport from the upland areas to the river within the study area because the majority of contaminants in groundwater are not present within this system.

#### 3.1.3.3 Groundwater Processes

Generally, groundwater flow adjacent to the study area is toward the river. The Tualatin Mountains (Portland West Hills) form a ridge that runs parallel to the Willamette River to the west, from the Multnomah Channel to the City of Portland. The mountains define the western edge of the Portland Basin; groundwater and creeks and channels along the east face of the mountains flow downward to the Willamette River. On the east side of the river, starting upstream of RM 4, a broad terrace divides the floodplains of the Willamette and Columbia rivers. Deep groundwater flows are influenced by the Columbia on the east side of the river, with effects increasing as distance from the Willamette River increases. Groundwater gradients are relatively flat in some areas along the east side of the river, due to both underlying geology and the influence of the Columbia River.

In the absence of preferential pathways, groundwater flow to the sediments and river will be diffuse along the length of the interface of each flow system with the river. However, permeability contrasts of several orders of magnitude can be expected in the FFA where alluvial processes create lenses and channels of sand within or surrounding finer-grained materials. The result of these permeability contrasts is that groundwater discharge will tend to be heavily influenced by the location and geometry of higher and lower permeability layers (e.g., sands or silts/clays) in relation to the river.

The groundwater flow regime zones bordering the river show seasonal patterns related to seasonal river stage and precipitation variations. The gradient and the resultant flux from these groundwater flow zones vary with seasonal river stage changes. Diurnal tidal stage changes also result in temporary gradient and thus flow changes, particularly where the degree of connection between the river and adjacent aquifer is greater.

Discharge of these groundwater flow systems through the river sediments to surface water is controlled by 1) the permeability contrast between the sediments and underlying aquifer, and 2) the difference between the hydraulic head in groundwater at the aquifer/sediment interface and the river stage, which determines hydraulic gradient. Full gradient reversals between the river and the adjacent groundwater flow systems are likely localized near the bank under most conditions because of the relatively high groundwater levels within the adjacent upland areas and resultant steep hydraulic gradients along the riverbank. However, very high river stages may produce larger temporary hydraulic gradient reversals that propagate further into the adjacent groundwater flow zones.

#### 3.1.3.4 Groundwater Flux Rates

Estimates of groundwater seepage rates from adjacent upland areas to the study area are available from several sources, as summarized below. They include direct measurements of groundwater seepage rates at selected locations within Portland Harbor, calculations of groundwater flux rates at upland sites that border the lower Willamette River, and estimates based on published regional groundwater modeling. All estimates are based on limited data and are subject to varying degrees of uncertainty. Additionally, groundwater flux rates are expected to be highly variable both spatially and temporally, due to localized and differing hydrogeologic conditions in the uplands that border the river, seasonal patterns in precipitation and groundwater recharge, and diurnal and seasonal variations in river stage.

##### 3.1.3.4.1 Seepage Meter Flux Measurements

Direct measurements of groundwater seepage rates to the river were taken during the LWG Round 2 investigation and during the offshore investigation performed by NW Natural at RM 6.2 (Anchor et al. 2007). Locations of these measurements are discussed in Section 2.1.3.1.8 and Appendix C2 of this RI report. Measurements were taken in nearshore areas as well as farther offshore, including several locations within the navigational channel. The seepage meters were installed on the west side of the river only, offshore from 9 upland sites in a total length covering about 8,800 ft of shoreline, representing about 6 percent of the total shoreline within Portland Harbor. In all, 77 ultrasonic seepage meter measurements were taken (70 LWG measurements and 7 non-LWG measurements), primarily during the summer and early fall months when groundwater flux toward the river is presumed to be relatively high due to low river stage, although this presumption has not been verified. Groundwater investigations at NW Natural (Anchor 2008d) indicate the highest gradients toward the river occurred in late March when the river stage drops, but groundwater levels in the uplands are still high due to recent precipitation and groundwater recharge.

These seepage meter measurements offshore of the nine study sites were taken in areas where contaminated groundwater plumes were suspected to be discharging to the river. Seepage meter deployment areas offshore of these sites and summary results for each area are presented in Maps 3.1-2-1a-i. At each measurement location, seepage measurements were collected at 15-minute intervals over deployment periods lasting at least 24 hours to capture diurnal variations in flux. The 15-minute seepage data were then time-integrated over one or more consecutive 24-hour periods to obtain estimates of daily average seepage rates. The 15-minute measured discharges ranged up to a maximum of 74 cm/day, and the lowest were about −30 cm/day. Daily average values ranged from a maximum of 14 cm/day to a minimum of −19 cm/day, with median values of about 4 cm/day in sand, and about 0.5 cm/day in sand/silt and silt (Figure 3.1-4). Measured groundwater flux rates showed substantial variability between measurement sites; in general, higher seepage rates were observed in sandy areas, and the lower values were observed in less conductive silt zones, as expected. A general decrease in measured seepage rates with increasing water depth was also evident, as illustrated in Figure 3.1-4.

The majority of measurements indicated net groundwater discharge to the river, consistent with the lower Willamette River's function as a sink for shallow groundwater discharge. Negative seepage values are interpreted to represent only very localized hydraulic interactions between the water column and channel bed, and do not indicate that surface water is significantly penetrating into upland groundwater flow zones bordering the river.

#### 3.1.3.4.2 Upland Groundwater Flux Rate Calculations

Appendix E of this RI report and a technical memorandum (*Upland Groundwater Flux Rates: Supporting Information and Calculations*; Integral 2015) present a discussion of the approach used to estimate groundwater discharge to the study area based on hydrogeologic data compiled for the RI for upland sites bordering the river and the application of Darcy's Law. Resulting values range from 0.1 to 3.8 cm/day, with a narrower range of 0.1 to 0.3 cm/day when certain values considered to be unrepresentative of regional conditions were excluded. This narrower range of unit groundwater fluxes is used in calculations of contaminant fluxes from subsurface and surface sediments driven by groundwater advection and equilibrium partitioning between sediments and the transition zone. These calculations are described in Section 6 and Appendix E of this RI report. Section 6 also includes a discussion of the limitations and uncertainties associated with the groundwater unit flux values used in support of the advective contaminant flux estimates.

#### 3.1.3.4.3 Modeled Groundwater Flux Estimates

A groundwater modeling study of the Portland Basin was performed by the USGS (Morgan and McFarland 1996; see Figure 14, p. 36). Over much of the study area, the reported discharge values are 1 cfs or less per model cell, with locally higher values in the range of 1 to 10 cfs per model cell. Taking the dimensions of each model cell into account (3,000 ft by 3,000 ft per side [Morgan and McFarland 1996; see p. 10]), these model estimates are equivalent to unit groundwater seepage rates of up to 0.3 cm/day into the lower Willamette River over much of the study area, with locally higher rates in the range of 0.3 to 3 cm/day.

Overall, the unit flux measurements obtained from seepage meters, particularly from sandy areas, are generally somewhat higher than the regional discharge estimates from modeling and Darcy's Law calculations. This difference may be attributable to selective placement of seepage meters in nearshore zones of likely or suspected groundwater discharge, where unit fluxes are likely to be higher than in finer-grained material and in deeper, mid-channel locations.

#### 3.1.3.5 Groundwater/Surface Water Transition Zone

The groundwater/surface water transition zone (Transition Zone) is the interval where both groundwater and surface water comprise some percentage of the water occupying pore space in the sediments (Figure 3.1-5). The physical and biochemical properties of water within the Transition Zone reflect the effects of mixing between groundwater and surface water that occurs within the sediments. The transition zone is significant to the RI because it is the location where important chemical (both natural and anthropogenic) and biological transformation processes occur that affect the properties of chemicals that may be present in TZW and sediment, and it encompasses the sediment biologically active zone where benthic infaunal ecological receptors may reside.

The zone of mixing between groundwater and surface water that defines the size of the Transition Zone exhibits temporal and spatial variability due to changes in gradients between the surface water and groundwater. The depth and degree of mixing also varies as a function of the magnitude and duration of diurnal and seasonal river stage changes, hydraulic properties of the sediment bed and aquifer materials, and spatial intersections of the river channel with the shallow, intermediate, and deep groundwater flow systems. Although temporary reversals in nearshore groundwater hydraulic gradients and flow direction occur in response to temporal changes in river stage, the net overall flux of groundwater is into the river, driven by the riverward groundwater hydraulic gradients within the adjacent upland flow system. The higher than average river stages associated with seasonal influences may drive more surface water into the sediment bed and the adjacent groundwater flow zones than reversals caused by shorter-term diurnal stage changes, but will not likely result in a significant overall increase in the degree of mixing of surface water with groundwater. Groundwater is expected to discharge at higher rates and, therefore, may comprise a greater percentage of the TZW in the shallower nearshore areas than in the deeper water locations where the deeper flow systems discharge to the river.

### 3.1.4 Surface Water Hydrology

River stage and currents in the lower Willamette River and Portland Harbor are influenced by hydrologic conditions in both the Willamette and Columbia rivers, and are further affected by the operations of federal and non-federal dams along these two rivers. River stage refers to the height of the river measured relative to a specific elevation or "datum." A variety of vertical datums are used in the Portland Harbor region, and these are discussed below.

#### 3.1.4.1 Regional Datums

Current or historical bathymetric and topographic data may be referenced to a variety of vertical datums in Portland Harbor. The bathymetric data collected as a part of this RI/FS are presented relative to NAVD88. This vertical datum is the national standard geodetic reference for heights and was selected for this project because it is a level datum and is easy to use with GPS. NAVD88 is a fixed datum derived from local MSL observations at Father Point/Rimouski, Quebec, Canada. NAVD88 replaced the National Geodetic Vertical Datum of 1929 through the Pacific Northwest Supplemental Adjustment of 1947 (NGVD29/47) as the national standard geodetic reference for heights.

NGVD29/47 is a fixed datum adopted and adjusted in 1947 as a national standard geodetic reference for heights prior to June 24, 1993, and is now considered superseded by NAVD88. NGVD29 is sometimes referred to as Sea Level Datum of 1929 or as MSL on some early issues of USGS topographic quads. NGVD29 was originally derived from observations at 26 long-term tide stations in the U.S. and Canada. Data referencing MSL as the vertical datum in the Portland Harbor are technically based on NGVD29/47.

CRD is used as the nautical chart datum for the lower Willamette River. CRD is a reference plane established by the USACE in 1912 by observing low water elevations at various points along the Columbia and Willamette rivers (USACE 1966). Consequently, CRD is not a fixed/level datum but slopes upward as one moves upstream. CRD is used upstream of RM 24 on the Columbia to the Bonneville Dam and on the Willamette River to Willamette Falls. Mariners can obtain the depth on a chart and apply tide or river-level gauge readings, relative to CRD, to compute actual water depth at the time of sailing. Low water values are used for navigation charting to provide conservative depth values in the event accurate tide data are not available to the mariner.

These three datums, NAVD88, NGVD29/47, and CRD, are the major datums used on maps and charts of Portland Harbor. The relationships or conversion factors between them are shown in Table 3.1-1 for the lower Willamette River to about RM 16 (Ross Island). In the lower Willamette, elevations reported relative to CRD are approximately 5 ft less than NAVD88 elevations (e.g., the –15 ft NAVD88 contour on LWG bathymetry maps equates to a –20 ft CRD elevation).

Water level (river stage) data measured by the Morrison Bridge gauge (RM 12.8) are recorded as the Portland River Datum (PRD) and are 1.55 ft above NGVD29/47 (USACE 1991). CRD is 1.85 ft above NGVD29/47 at the Morrison Bridge. On December 27, 2001, DEA confirmed the relationship between this gauge and CRD by running a differential leveling circuit from a nearby control monument used in the control network for the Willamette multibeam surveys. This survey confirmed that the Morrison Street staff gauge reports water levels 0.30 ft above CRD, as defined by the USACE (1991).

The river stages discussed in this section are the directly measured Morrison Bridge gauge levels and are therefore reported as PRD elevations in feet. To convert from PRD to CRD, subtract 0.3 ft from the reported river level. The datum relationships discussed for Portland Harbor above are illustrated in Figure 3.1-6.

#### 3.1.4.2 Regional Hydrology

The Columbia River drains a large segment of the northwestern United States and parts of western Canada. The Columbia basin is so large that isolated events such as localized rainstorms may have little or no effect on river flow. In its natural state, high flows on the Columbia River are most influenced by snow melt, which takes place during the spring months. This results in high water typically occurring in late May or early June, followed by receding water levels until the rains begin in late fall.

Lowest water on the Columbia River typically occurs in October or early November, reflecting a lack of precipitation and snowmelt in the basin during the summer months. With the onset of winter rains and snow, runoff will vary during the winter months, until the spring snowmelt leads to the high water period.

The Willamette River is a major tributary of the Columbia River and flows into the river at Columbia River Mile 103. Over the water years 1973 through 2007—a 35-year period of record—the Willamette River average daily mean discharge was 33,000 cfs, while that of the Columbia River above the confluence of the Willamette was 177,000 cfs.[2]

The lowest water levels in the Willamette, as in the Columbia, typically occur between September and early November prior to the initiation of the winter rains. Unlike the Columbia River, however, Willamette River flows generally increase in response to regional storms due to the comparatively small size of the basin. Record winter floods (e.g., 1964 and 1996) occurred when periods of heavy snowfall at lower elevations were followed by warming periods and heavy rains, resulting in rapid increases in runoff.

Figure 3.1-7 shows a plot of the mean daily river stage data (reported in feet, PRD) measured by the USGS gauge #14211720 on the Morrison Bridge in Portland near RM 12.8 from October 1972 through March 2008. The seasonal water level trends described above are evident in this plot. Low water typically occurs during the regional dry season from August to November. Winter (November to March) river stage is relatively high but variable due to short-term changes in precipitation levels in the Willamette basin. Finally, a distinct and persistent period of relative high water occurs from late May through June when the Willamette River flow into the Columbia is slowed during the spring freshet by the high-water stage in the Columbia River.

[2] The average daily mean values noted are based on data from the USGS gauge #14211720 (Willamette River at Portland, OR) and from USGS gauge #14105700 (Columbia River at The Dalles, OR), which is located downstream of the confluence of the Willamette but is the closest USGS gauge for which data are available for water years 1973–2007. These data are available at: http://waterdata.usgs.gov/nwis/sw.

### 3.1.4.3 Willamette River Hydrology

River stage and currents in the lower Willamette River and Portland Harbor are influenced by hydrologic conditions in both the Willamette and Columbia rivers, and are further affected by the operations of federal and non-federal dams along these two rivers. River stage refers to the height of the river measured relative to a specific elevation or "datum" which is discussed in Section 3.1.4.1.

Recent investigations of the hydrodynamics of the lower Willamette River, study area, and Multnomah Channel are summarized in this section. Both empirical information (flow measurements) and HST modeling (WEST and Tetra Tech 2009) have been conducted as part of this RI to support the understanding of the physical system and hydrodynamics. The primary objective of these efforts for the RI was to gain a sufficient understanding of the physical system to support the RI site characterization, the BHHRA, the BERA, and site-wide fate and transport modeling.

#### 3.1.4.3.1 Stages and Discharges

Lowest water in the Willamette, as in the Columbia, typically occurs between September and early November prior to the initiation of the winter rains. With the onset of the rains, flows in the Willamette will generally increase, sometimes in rapid (several days) response to regional storms. The record winter floods (e.g., 1964 and 1996) occurred when a period of heavy snowfall at lower elevations was followed by a period of warming and heavy rains. The combination of the snowmelt and rain leads to exceptionally high runoff that occurs rapidly due to the small size of the basin as compared, for example, with the Columbia River basin.

The effect of the multipurpose dams on the Columbia River and its tributaries has been to generally reduce the spring high water flows through ponding of the excess water to the extent permitted by the capacity of the reservoirs at each of the dams. Starting in late summer, this stored water is released, which increases flows above the low flows that would otherwise occur. By winter, these reservoirs have been drawn down and the reservoir capacity is used to take the peak off of winter flows and to optimize the generation of electricity.

There are 13 federal reservoirs on the Willamette River and its tributaries, having a combined storage capacity of over 1.6 million acre-feet. These reservoirs reduce the river flow during the winter snow and rain events by storing water. With each major storm, water is stored and then released at the end of the storm to smooth out the flow of the river. During persistent rainy periods and/or during exceptionally large precipitation events, the storage capacity may be exceeded, and additional flow entering the system leads to flooding, as occurred in 1964 and 1996. During these flood events, water flow in the river can be up to 50 times greater than the flow during low-water periods. Late in the winter, after the probability of a major flooding event has passed, the reservoirs are filled to capacity. These reservoirs are used for low flows and to provide storage capacity in preparation for the flood season.

Water levels and currents in the lower Willamette River can be influenced by the Columbia River in several ways. The most apparent influence occurs during spring when high flows from the Columbia River increase the hydraulic head at the confluence of the two rivers and cause the Willamette River flow to be detained (Figure 3.1-7). When this occurs, currents in the Willamette are much reduced due to the elevated river stage in the Columbia River. As the Columbia River drops, the Willamette water level will also drop and flows will increase to more typical conditions.

A less obvious influence can occur in the winter when the Willamette River is in flood. The flows on the Columbia River can be held back by its dam system, which has the effect of lowering the backwater effect of the Columbia and thus dropping the levels in Portland Harbor below their typical condition. This mechanism was used in the 1996 flood to reduce the flood levels of the lower Willamette River, including Portland Harbor.

Tidal action also compounds the hydrology and interplay of the two rivers, and affects the Willamette River upstream as far as Portland Harbor and beyond. Tides along the North American West Coast are mixed semidiurnal (two unequal high tides and two unequal low tides daily), with an average tidal range of approximately 8 ft in the Pacific Ocean. The high tide can influence Willamette River levels by up to 3 ft in Portland Harbor when the river is at a low stage. These tidal fluctuations can result in short-term flow reversals (i.e., upstream flow) in Portland Harbor during times of extremely low river stage combined with a large variation in tide levels, which can occur in late summer to early fall. This effect was measured in May 2003 as part of the bathymetry survey effort using an acoustic Doppler current meter (DEA 2003c). As river stage rises, the tidal effect is gradually dampened and disappears at river levels around 10 ft CRD.

### *USGS Gauge Data*

Figure 3.1-7 shows a plot of the mean daily river stage data (reported in feet PRD) from October 1, 1972 through March 31, 2008 at the Morrison Bridge in Portland near RM 12.8 (USGS gauge #14211720).[3] Mean historical daily discharge (cfs) calculations from this gauge are shown in Figure 3.1-8, and Figure 3.1-9 presents the annual average discharges by water year[4] over the period of record. Flow data from October 1972 to September 1994 were computed by the USGS using an acoustic velocity meter (Lee 2002, pers. comm.). Most data after September 1994 are USGS estimates based on measurements from regional stations (Miller 2006, pers. comm.).

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[3] Data obtained from Regulation and Water Quality Section Web site (http://www.nwd-wc.usace.army.mil/perl/dataquery.pl?k=id:PRTO+record://PRTO/HG//1DAY/MEAN/) and the USGS National Water Information System Web site (http://waterdata.usgs.gov/or/nwis/uv?14211720). Where USGS data are available, they replaced USACE data for compiling the graphs shown in this section. The USACE site notes that these “data have not been verified and may contain bad and/or missing data and are only provisional and subject to revision and significant change.” The data are used here only to illustrate long-term relative trends in the Willamette River stage at Portland. No data are available for 1991 and 1992.

[4] A water year extends from October 1 to September 30 (e.g., October 1, 1972 to September 30, 1973 comprises the 1973 water year).

The seasonal cycle of water levels on the Willamette River is illustrated in Figure 3.1-7. Annual low water levels typically occur during the regional dry season from August to November. Winter (November to March) river stage is relatively high but variable due to short-term changes in precipitation levels in the Willamette basin. Finally, a distinct and persistent period of relatively high water levels occurs from late May through June when Willamette River flow into the Columbia is slowed by high-water stage/flow in the Columbia River during the spring freshet in the much larger Columbia River Basin, as described above.

The two highest peaks in the daily mean discharge record occurred in the winters of 1996 and 1997, when peak flows reached 420,000 cfs on February 9, 1996 and 293,000 cfs on January 2, 1997 (Figure 3.1-8). For the water years 1973 through 2007—a 35-year period of record—the mean annual daily discharge was between 20,000 and 30,000 cfs during 14 years of this period (Figure 3.1-9). Annual mean daily flows were above 30,000 cfs during 19 years, with 7 of those years above 40,000 cfs, and 3 years in excess of 50,000 cfs. Only two water years (1977 and 2001) had average daily flows between 10,000 and 20,000 cfs. Figure 3.1-10 presents the frequency (number of days per year) distribution of daily mean discharge values from the October 1, 1972 through March 31, 2008 data set. Flow on the Willamette River is most often between 10,000 and 30,000 cfs. Approximately 75 percent of the time flows are less than about 40,000 cfs, and exceed 90,000 cfs less than 10 percent of the time.

Figures 3.1-11a–h show river stage data through each of the RI sample-collection years (i.e., 2001–March 31, 2008). For comparison, the graphs also include a plot of average annual river stage values based on the entire period of record (October 1972–March 2008), and plots of the values within one and two standard deviations from the average (representing approximately 68 percent and 95 percent of the recorded values, respectively). The lower Willamette River flood stage (18.3 ft PRD [18 ft CRD]) was not reached during the RI sampling period.

The lower Willamette River discharge rates during the RI years followed a typical seasonal pattern and, as with river stage levels, were generally within the range of typical discharges on record. Figures 3.1-12a–h present plots of river discharge data through each of the RI years (2001–March 31, 2008), with plots of the average daily discharge (October 1, 1972–March 31, 2008) and values within one and two standard deviations from the average shown for comparison. Early 2001 and early 2005 were relatively low-flow winter/spring periods and early and late 2006 had relatively high flows compared with the long-term averages.

***ADCP Surveys***

Flows were also measured by the LWG at multiple locations in the lower Willamette River using an ADCP during three of the four time-series bathymetric surveys which were conducted to measure riverbed elevation changes over time (see Section 3.1.6.2). The ADCP data provided snapshot observations of flows in the study area across a range of flow and tidal conditions (DEA 2002b, 2003c, 2004b). The empirical flow data also supported the development and calibration of a hydrodynamic model developed for this RI/FS (WEST and Integral 2005). The model output shows that currents generally flow downstream during four of the six flow-tide combinations. Reverse or upstream flows occur when river flow is low and the tide is in flood.

In general, flow in many of the relatively shallow nearshore embayments and slips is characterized by eddies and/or inshore flow, except on ebbing tides during low-flow periods, when downstream or offshore flow directions are dominant. As expected, higher current speeds occur in the deeper portions of the river channel, and lower speeds occur in the shallow nearshore areas, regardless of flow direction. Flow in Multnomah Channel is downstream under all flow/tide combinations modeled.

During high flows on the Willamette and comparable flows on the Columbia (Figures 3.1-13a–h), flow is consistently downstream on the lower Willamette River, and the model predicts that there is an apparent eddy effect (reduced circular flows) where the Willamette River flows into the Columbia River.

The flow data collected during the ADCP surveys in April 2002, May 2003, and January 2004 suggested that lower Willamette River discharge through Multnomah Channel could be significant, ranging from 25 to 50 percent of the discharge volume of the Willamette during the “snap-shot” ADCP measurement periods. The percentage of Willamette River flow through Multnomah Channel is a function of the relative flow regimes in the Willamette and Columbia rivers, as well as tidal stage.

***Multnomah Channel Flows***

To investigate Multnomah Channel flows on a more continuous temporal basis, the CE-QUAL-W2 hydrodynamic model of the Columbia River/Willamette River System developed by Portland State University was used to model daily average flows in the system over a nearly 4-year period from January 1999 through December 2002 (Integral 2006q). Figure 3.1-14 shows the flows (daily average cubic meters per second) for the Willamette and Columbia rivers and the modeled flows for the Multnomah Channel over the 1,400+-day (approximately 4-year) model run. The figure also shows the fraction of the total Willamette River flow through Multnomah Channel (black line). “Fraction” values greater than 1 indicate that flow down Multnomah Channel exceeds the Willamette River flow upstream of Multnomah Channel (i.e., at these times, Multnomah Channel flows are a mixture of Willamette River water and inflow from the Columbia River).

The modeling effort identified three distinct river flow combinations and evaluated the proportion of discharge carried by Multnomah Channel:

- **Low flows in both the Columbia River and Willamette River—**When flows are relatively low in both the Willamette and Columbia rivers, about 50 to 60 percent of the Willamette flow goes down Multnomah Channel.

- **Low flow in the Columbia River and high flow in the Willamette River—** When relatively high flows in the Willamette River are concurrent with relatively low flows in the Columbia River, the proportion of Willamette River flow carried by Multnomah Channel decreases to about 25 to 30 percent of the total Willamette River flow.
- **High flow in the Columbia River and low flow in the Willamette River—** When Columbia River flows are high and Willamette River flows are low, the increased river stage at the Columbia/Willamette confluence forces much of the Willamette River flow down Multnomah Channel. At certain low-flow Willamette periods (summer/early fall), all of the Willamette River flow, in terms of daily average volumes, plus some flow from the Columbia River, goes down Multnomah Channel. This last condition occurs about 25 percent of the time over the period modeled (January 1999 to December 2002).

No clear periods of concurrent high flows in both the Willamette River and Multnomah Channel were identified within the nearly 4-year model simulation period. Averaged over the study period, flows in Multnomah Channel represent about 60 percent of the Willamette River flow upstream of Multnomah Channel. It should be kept in mind that some of the Multnomah Channel flow is Columbia River water, but the relative volumes of Willamette River versus Columbia River water flowing down Multnomah Channel cannot be determined from these modeling results.

#### 3.1.4.3.2 Velocities and Currents

Velocity data for the lower Willamette River consists mainly of data collected over the years by the USGS. From July 1962 to January 1965, the USGS measured velocities at the Broadway Bridge near RM 11.7 and the Ross Island Bridge near RM 14. Stream flow conditions varied from low tidal-affected flows to near maximum flood of record during December 1964. Measured cross-sectional mean velocities ranged from a maximum of 8 ft/s downstream during the December 1964 flood to a low upstream velocity of nearly 1 ft/s during a tidal cycle on October 15-16, 1963 (Dempster and Lutz 1968).

From October 1972 to September 1994, the USGS maintained an acoustic velocity meter with water stage and velocity index recorder at the Morrison Bridge gauge near RM 12.8. During that time period, rating curves were periodically updated with velocity measurements at the gauge location over a range of flow conditions. On January 14, 2000, the USGS collected isolated transects of instantaneous velocity data using a vessel-mounted ADCP (Wood 2013 per. comm.). Transects were collected at RM 12.8, a relatively narrow stretch of the river, and near RM 4.1, a broader stretch of the river (Barrett 2002; Wood 2002). Mean velocity and discharge at RM 12.8[5] were 2.65 ft/s and 111,500 cfs respectively, and 1.41 ft/s and 118,300 cfs at RM 4.1[6].

[5] Data collection was from 13:08 hrs. to 13:42 hrs.
[6] Data collection was from 15:25 hrs. to 16:30 hrs.

Flows were measured by the LWG at multiple locations in the lower Willamette River using an ADCP during three of the four time-series bathymetric surveys which were conducted to measure riverbed elevation changes over time (see Section 3.1.6.2 for discussion on bathymetric surveys). The ADCP data provided snapshot observations of flows in the study area across a range of flow and tidal conditions (DEA 2002b, 2003c, 2004b). The first survey was conducted on April 19, 2002 along 16 transects from RM 1 to 11 during a high-water event. The second survey occurred on May 13, 2003. ADCP profiles were collected in the vicinity of the Multnomah Channel (RM 3) to understand the flows to the Multnomah Channel. On January 31, 2004, a third ADCP survey was conducted during a relatively high-flow event along the same 17 transects sampled in the previous two studies. Detailed ADCP survey and data processing methods are described in the ADCP Survey Reports (DEA 2002b, 2003c, 2004b).

***April 2002 Survey***

ADCP data were collected by DEA for the LWG during a high-water event on April 19, 2002 (DEA 2002b). The transects were located at RM 1, 2, 2.5, 3.1 (Multnomah Channel), 4, 4.6 (into Terminal 4 Slip 3), 5.8 (St. Johns Bridge), 6.3 (off Gasco), 6.8 (into Willamette Cove), 7.8 (off Willbridge Terminal), 8 (from Coast Guard Station, across shipyard to west bank), Swan Island Lagoon (2 short transects—one across mouth, one at upper end), 9.6, 10, and 11. The river stage at the time of the data collection was approximately 11.6 ft CRD (11.9 ft PRD) at the Morrison Street Bridge (Figure 3.1-11b; DEA 2002b).

Water velocities obtained from the ADCP survey ranged from an upstream velocity of nearly 1 ft/s (upstream flow in back eddy) to a downstream velocity of 2 ft/s. Flows across the transects were computed at approximately 70,000 cfs above Multnomah Channel and approximately 35,000 cfs below Multnomah Channel. The Willamette flow on April 19, 2002 was roughly double the average Willamette discharge rate of about 32,000 cfs. Table 3.1-2 summarizes ADCP transect time, location, and approximate total flow.

Figure 3.1-15a presents ADCP data at Transect 11 at RM 8, just downstream of Swan Island and the Portland Shipyard. These two transects were selected because they illustrate some flow regimes that are atypical of the general flow patterns seen during this survey. Both the vector plot (Figure 3.1-15a) and velocity profile (Figure 3.1-15b) reveal a sharp drop in velocity behind Swan Island and a small back eddy into Swan Island Lagoon. The velocity profile in Figure 3.1-15b also illustrates some vertical structure with increased flows in the upper water column in mid-channel.

Figure 3.1-16a presents the measured ADCP data at Transect 14 at RM 9.6 across the deep dredged hole off of Swan Island. An increase in the water column average velocities can be seen in Figure 3.1-16b. A back eddy can be observed in both the vector plot and the velocity profile. The velocity profile also shows strong near-bottom velocities in the hole with increased velocity toward the water surface.

### *May 2003 Survey*

On May 13, 2003, multiple ADCP profiles were collected along the three transects in the lower Willamette River in the vicinity of the Multnomah Channel (RM 3), and a fourth transect was located within Multnomah Channel. ADCP profiles were repeated 5 to 6 times along each transect over a 14-hour period to capture ADCP data over a complete tidal cycle. The complete results of this effort have been documented by DEA (2003c).

Table 3.1-3 shows the discharges (Q, $ft^3/s$) observed along the four transects of the May 2003 survey during each ADCP pass. Positive values equal net downstream discharge in the lower Willamette River and Multnomah Channel. Note that discharge, Q, does not equate directly to flow velocities because the cross-sectional area of the river varies from place-to-place. Net discharge was downstream along all transects over the entire tidal cycle with two exceptions: during the maximum flood tide (Pass 5), net discharge was upstream at Transect 3 (downstream of Multnomah Channel) and at Transect 4 (at the Multnomah Channel head). Water velocities along the transects were relatively steady during Passes 1 to 3, the ebb tide. Velocities averaged from 0.25 to 0.5 ft/s in the lower Willamette River channel. Velocities were slightly higher (0.5 to 1.0 ft/s) in Multnomah Channel. Near low tide, Pass 4, water velocities in the lower Willamette River slowed and began to reverse direction, first along the eastern bank and propagating westward. By Pass 5, the flood tide, the water flow was completely upstream at Transect 3, and reversed direction along the eastern half of the lower Willamette River at Transect 4, and along a narrow portion of the eastern bank at Transect 5. By Pass 6, the high tide, flow velocities, both in direction and magnitude, were comparable those seen during the morning ebb tide.

### *January 2004 Survey*

A third ADCP survey was conducted on January 31, 2004 to provide data on current velocities during a high-flow event. The results of this effort have been documented in the survey results report (DEA 2004b). Seventeen transects between RM 0 and 11 were profiled over a 9-hour period during a 130,000 cfs flood event (DEA 2004b). Selected transects near the head of Multnomah Channel (3, 4, 5, and 17) were run once in the morning on a rising tide, and again in the afternoon on a falling tide (DEA 2004b). The discharge (Q) data from these transects are included in Table 3.1-3. Measured discharges just upstream of Multnomah Channel, Transect 5, peaked at about 130,000 cfs during this high-flow event; this is 3 to 4 times greater than the peak discharges measured in May 2003. Based on the measured discharges in Multnomah Channel, approximately 25 percent of the Willamette flow was exiting the system down the channel during the high-flow event. During the lower flow period in May 2003, over 50 percent of the Willamette flow was discharging down Multnomah Channel during the ebbing tide.

Plots of the winter 2004 transect data are shown in Figures 3.1-17a–t. The data indicate that flow is predominantly downstream throughout the survey, with current speeds up to a maximum of 3.5 ft/sec observed at RM 11.0 (Transect 16; Figure 3.1-17t). Lower maximum velocities on the order of approximately 2.5 ft/s are observed in the downstream transects, particularly downstream of Multnomah Channel (Figures 3.1-17a-d). Areas of relatively sluggish flow or eddies are apparent on the margins of certain transects that enter relatively shallow or protected areas (Transects 3, 6, 9, 10), and across the entrance to Swan Island Lagoon (Figures 3.1-17c, d, k, n, and o). River level readings from the Morrison Street gauge at RM 12.8 at the time of the survey display a tidal signal, indicating that the tidal influence on river levels was not overridden by the high-flow event (DEA 2004b).

The empirical flow data detailed above supported the development and calibration of a hydrodynamic model developed for this RI (WEST and Integral 2005). The revised Phase 2 HST model (WEST and Tetra Tech 2009) was used here to develop vector plots of current velocities throughout the study area during both mid-ebb and mid-flood tides for both high- and low-river-flow periods (Figures 3.1-18a through 3.1-21c). Vector plots were also generated that show current velocities during maximum flood tide coupled with low river flow (Figures 3.1-22a–h) for the entire lower Willamette River (to assess the maximum extent of upstream flow reversals) and during high flows in both the Willamette and Columbia rivers (Figures 3.1-13a–h). Lower Columbia and Willamette flow and stage data are included in footnotes on the vector plots.

The model output shows that currents generally flow downstream during four of the six flow-tide combinations. Reverse or upstream flows occur when river flow is low and the tide is in flood.

In general, flow in many of the relatively shallow nearshore embayments and slips is characterized by eddies and/or inshore flow, except on ebbing tides during low-flow periods, when downstream or offshore flow directions are dominant. As expected, higher current speeds occur in the deeper portions of the river channel, and lower speeds occur in the shallow nearshore areas, regardless of flow direction. Flow in Multnomah Channel is downstream under all flow/tide combinations modeled.

Based on this hydrodynamic model output, at the maximum flood tide during the low-flow period, reversed flows extend upstream to approximately RM 15, where upstream flow velocities are minimal, approximately 0.2 ft per second in the channel (Figures 3.1-22a–h), and are very low upstream of RM 15 to about RM 18.

During high flows on the Willamette and comparable flows on the Columbia (Figures 3.1-13a–h), flow is consistently downstream on the lower Willamette River, and the model predicts that there is an apparent eddy effect (reduced circular flows) where the Willamette River flows into the Columbia River.

The ADCP data were all collected during periods of high flow in the Willamette River (DEA 2002b, 2003c, 2004b). Data collection occurred during the day, typically within the 12-hour window between 6:00 a.m. and 6:00 p.m. Consequently, the ADCP data along the study reach are more variable with respect to tides than the HST model output, which encompasses the entire reach under a given tide stage. Additionally, the

ADCP results are not readily comparable to the low-flow model scenarios. That said, the following general observations between the ADCP current data and the HST model (assuming high Willamette River flow) can be made:

- The ADCP results and the HST model both indicate that under high-flow conditions, the Willamette River has an overall net downstream flow direction. Further, the May 2003 ADCP data (which were collected from repeat measures along several transects over the course of a day to capture different tide stages) agree with the model that flow direction reversals do occur in nearshore areas, regardless of tide level and can also occur in the main river channel during flood tide.
- Both the ADCP results and the HST model show higher flow velocities in the deeper, open water areas of the channel relative to nearshore, shallower areas. The model predicts main channel velocities of approximately 50 cm/s (or about 1.6 ft/s), with higher velocities occurring upstream relative to downstream. The ADCP results exhibit a similar pattern: main channel velocities typically ranged from 39 to 61 cm/s (1.3 to 2 ft/s), with the upper reaches having velocities as high as 76 to 91 cm/s (2.5 to 3 ft/s) during very high-flow events, as evidenced from the April 2004 ADCP event.

### 3.1.5 Soils

#### 3.1.5.1 Regional Soils

The regional soils in the vicinity of the Site are composed of Sauvie-Rafton-Pilchuck soils (about 30 percent Sauvie soils, 10 percent Rafton soils, 10 percent Pilchuck, and 50 percent soils of minor extent and Urban land) that consist of silt loams, silty clay loams, and sands (NRCS 1983). They formed in recent alluvium. These soils are generally underlain by coarse or moderately course alluvium below a depth of 60 inches. Slopes range from nearly level to moderately steep (0 to 15 percent) soils on bottom lands, and elevation ranges from 10 to 20 ft (NRCS 1983).

The Sauvie soils have a surface layer of very dark grayish brown silt loam and a subsoil of dark grayish brown, mottled silty clay loam. The substratum is dark grayish brown, mottled silt loam over fine sandy loam to a depth of 60 inches or more (NRCS 1983).

The Rafton soils have a surface layer of dark grayish brown, mottled silt loam and a subsoil of grayish brown and brown mottled silt loam. The substratum is dark grayish brown silt loam over black silt loam to a depth of 60 inches or more. These soils are subject to frequent flooding from December to July and in places are subject to ponding in July (NRCS 1983).

The Pilchuck soils have a surface layer of very dark grayish brown sand. The substratum is dark grayish brown sand to a depth of 60 inches or more (NRCS 1983). Sandy material dredged from the river channel is in some areas of Pilchuck soils.

Of minor extent in this area are the somewhat excessively drained Burlington fine sandy loam, the poorly drained Faloma silt loam, the very poorly drained Moag silty clay loam, and the somewhat excessively drained Sifton gravelly loam soils (NRCS 1983). The Burlington is on long narrow terraces, generally above an elevation of 20 ft. The Faloma soil has a sandy substratum. The Moag soil is in convex areas. The Sifton soil is on terraces, generally above an elevation of 20 ft. Other soils found in this area include Urban land, Riverwash, and water areas (NRCS 1983).

#### 3.1.5.2 River Sediments

Several types of investigations have been conducted as part of the RI to characterize the physical nature of bedded sediments and their potential for movement within and through the lower Willamette River due to natural or anthropogenic forces. Additionally, a numerical HST model was developed (Integral and WEST 2006; WEST 2004, 2005; WEST and Integral 2005, 2006; WEST and Tetra Tech 2009) and used to predict physical characteristics where they were not measured and the potential impact of extreme (flood) events on Site sediments, particularly the potential for buried contaminated sediments to be re-exposed.

The sections that follow provide an overview of the major physical system Site information, including sediment characteristics and a description of the major sediment transport regimes based on this body of empirical and modeling information.

##### 3.1.5.2.1 Physical Characteristics

The physical properties of sediments yield significant information regarding the physical dynamics of the river system. Physical sediment data (e.g., grain size, specific gravity, total solids) and TOC have been collected as part of all sediment sampling for the RI and are also available from other sampling efforts conducted in the lower Willamette River (see Table 2.0-1). TOC in river sediments comes from decaying natural organic matter and from synthetic sources (e.g., detergents, pesticides, fertilizers, herbicides, industrial chemicals, and chlorinated organics) and is usually associated with fine-grained or silty sediments.

The interval from 0 to 30 cm bml was used to define surface sediments within the lower Willamette River. This surface sediment interval definition was based on the empirical bathymetric change data, which indicate that most changes to the riverbed (e.g., erosion and deposition) occur within this interval under typical conditions within the study area. Below 30 cm, LWG-collected subsurface core samples were processed such that major discontinuities in sediment texture (e.g., sand/silt) were used to define subsurface sample breaks (see Integral, Anchor, and Windward 2004).

The grain-size data measured in surface sediment samples in the RI database were used to generate contour maps of surface sediment grain size (as percent fines[7]; i.e., coarse

[7] Fines are defined as sediments less than 63 microns in diameter that would pass through a through a No. 230 U.S. Standard sieve mesh. Based on the Wentworth Size Class, this includes coarse silt, medium silt, fine silt, very fine silt, and clay. This combined silt and clay fraction is also referred to as mud on the Wentworth scale.

silt [63 µ] and finer) and TOC (percent) in the study area (Maps 3.1-3 and 3.1-4). In the absence of anthropogenic activities that affect sediment textures, the physical characteristics of surface-bedded sediment are general indicators of the energy regime of the riverbed at that location. Typically, fine-grained sediments (silts, clays) dominate in relatively low-energy environments where current velocities are low enough to allow fine particles to settle out of the water column and remain deposited, whereas coarse sediments (sands, gravels) are indicative of higher-energy environments where fines are kept in suspension in the water column and/or winnowed out of previously deposited material and transported away during transitory high-energy events (e.g., floods or anthropogenic disturbances, such as prop wash, wave action, dredging, etc.).

The sediment samples compiled for the RI from the confluence with the Columbia River to Willamette Falls at RM 26 exhibit a large variety of sediment types ranging from sandy gravels to mud (i.e., silts and clays combined). The majority of the sediments over this 26-mile reach are sands or muddy sands, with more course grained sediments found in the relatively high energy areas upstream of the study area (i.e., RM 11 to 26). The general characteristics of the upriver and downtown reaches compared with the study area are summarized below. These descriptions are based on an initial survey of surface sediment textures described in GeoSea Consulting (2001). Further details on the regional sediment transport regimes are presented in Section 3.1.5.2.6.).

#### *Upriver Reach*

In the upriver reach from RM 15.3 to 26, the river is confined in Tertiary basalt, which outcrops on much of its bottom. The Clackamas River brings some sand into the river, and there are pockets of reworked sand and some finer-grained sediments along the margins and in backwaters. Much of the bottom is hard ground in this area. Where sediment is found, it is predominately sand or gravelly sand, but there are pockets of muddy sand near banks and in some sheltered locations. Coarse sandy sediment occurs downstream of Oswego Creek, which drains Lake Oswego and may account for the accretion of sediments in this area.

#### *Downtown Reach*

A mix of sediments characterizes the downtown reach from RM 11.8 to 15.3, but they consist mostly of either sand or muddy sand. Silts and clays (mud) are found along the western margins of the lagoon inside Ross Island, where historical aggregate mining took place. Some hard ground is also found in this reach, but in more isolated and smaller areas than in the upriver reach. Between Elk Rock Island and the vicinity of the Marquam Fixed Bridge, the river generally widens and flows through Pleistocene sediments, with the result that sediments contain somewhat more mud than in the upriver reach. The sediments from inside the lagoon in Ross Island are generally much finer grained than the sediments in the adjacent channel. Fine sediment entering the lagoon likely settles inside the lagoon, although there is constant human activity taking place.

### *RI Study Area Reach*

The river widens as it enters the RI study area reach. At the upstream end of the study rea (RM 11.8), Map 3.1-3 shows that sandy surface deposits (i.e., 0–20 percent fines [silts and clays or mud]) are predominant from upstream of the study area downstream to RM 11, especially along the western half of the river. The river gradually widens from RM 10 to 11, and this area is a mosaic of predominately sandy sediments (21–40 percent fines) and mixed muddy sand and sandy mud (41–60 percent fines) textures. Deeper holes and nearshore areas and embayments are dominated by muds (61–100 percent fines).

The river widens markedly from RM 7 to 10, and surface sediments are dominated by fines, with the exception of some nearshore bank areas and some discontinuous areas along the western edge of the navigation channel. The finest texture sediments (81–100 percent fines) are widespread from RM 7 to 9, including locations within Willbridge Terminal, in the downstream lee of Swan Island (Portland Shipyard), and in Swan Island Lagoon.

From about RM 5 to 7, the river and navigation channel narrows again, and this reach is dominated by sands with relatively small subareas (e.g., within Willamette Cove and western nearshore around RM 6) that are dominated by fines characteristic of lower energy environments. Much of the remainder of the study area and beyond, to about RM 1.5, is dominated by fines, with a texture of 61–80 percent fines dominant upstream of Multnomah Channel (RM 3–5) and 81–100 percent fines widespread downstream of Multnomah Channel (RM 1.5–3). Conversely, the relatively shallow and narrow Multnomah Channel is dominated by sands, as is a portion of the study area upstream and immediately adjacent to the Multnomah Channel entrance extending to the east bank. This is the largest area in the lower Willamette River between RM 1.5 and 5 that is not dominated by fines.

As expected, the TOC content of the surface sediments (Map 3.1-4) generally mirrors the sediment grain-size distribution, with higher TOC content collocated with the finer-grained deposits. TOC levels generally range from 0.5 to approximately 3 percent, but a few isolated areas contain higher levels (6 to up to 27 percent); these are all downstream of RM 7 and include the head of Willamette Cove, an area west of the main channel from RM 6.2 to 6.4, a mid-channel area at RM 5.7, and a relatively large area east of the channel at RM 2.

Vertical gradients in grain size can be examined visually across the study area by comparing Map 3.1-3 (contoured surface sediment texture; i.e., upper 30 cm, 1 ft) with Map 3.1-5 (contoured sediment texture for the shallow subsurface horizon; i.e., subsurface intervals ranging between 1 and 5 ft on average). Overall, the surface and shallow subsurface sediment textures are consistent throughout the study area, suggesting that the current energy regimes in the system are relatively stable. There is, however, a subtle but perceptible widespread shift from finer-grained surface sediments to a slightly coarser-grained subsurface layer (e.g., from 81–100 percent fines to 61–

80 percent fines) across much of the site. This may reflect seasonal or inter-annual winnowing of the finer sediments from the sediment bed during higher flow periods and the subsequent long-term burial of the slightly coarser residual sediments. Finally, there are three areas that show distinctly coarser surface sediments overlying finer material; these include the head of Swan Island Lagoon, the McCormick and Baxter/Willamette Cove area, and the area outside the entrance to Multnomah Channel, extending into the channel itself. Anthropogenic placement of fill at the head of Swan Island Lagoon by 1975 and the sand cap cover placed in the river and beach at the McCormick and Baxter Creosoting Company (McCormick and Baxter) site in 2005 appear to explain this pattern in Swan Island Lagoon and around McCormick and Baxter/Willamette Cove, respectively. The vertical shift to finer material at depth immediately adjacent to and within the mouth of the Multnomah Channel is not as apparent, but the "relict" muds may reflect the less dynamic sedimentary environment that existed in this portion of the river prior to the Portland Harbor navigation channel dredging and other land use modifications in the region (e.g., bank treatments).

#### 3.1.5.2.2 Riverbed Elevation Changes

Riverbed elevations changes are presented as changes in bathymetry measured at overlapping locations for two points in time. While several bathymetric surveys were conducted throughout the RI, the January 2002 and January 2009 surveys have been selected to represent the long-term changes in bathymetry. The January 2002 survey was conducted by the LWG (Section 2.1.1.1) and the January 2009 survey was conducted by NOAA. Section 3.1.6.2 discusses all the bathymetric surveys conducted in the lower Willamette River during the RI. Map 3.1-6 was created by overlaying the 1-m cells from each survey and subtracting the January 2009 data from the January 2002 data (the depth values are generally negative numbers, e.g., –15 ft NAVD88) to generate a direction and magnitude of change for each cell. The vertical resolution of the multibeam survey overlay was ±0.25 ft (approximately 7.6 cm), so cell comparisons that show positive or negative changes less than or equal to 0.25 ft represent no discernible change in riverbed elevation. Map 3.1-6 shows the net bathymetric change over the 7-year period between the first (January 2002) survey and the January 2009 survey in the lower Willamette River. This time frame includes a winter (late 2005-2006) where there was a prolonged period of relatively high flows approach 200,000 cfs.

Map 3.1-6 presents positive elevation changes (shallower in 2009 compared to 2002) indicate shoaling, and negative elevation changes (deeper in 2009 compared to 2002) indicate deepening. The no-change areas are shaded gray, while shoaling areas (positive change) are shown in yellow to orange shades, and areas that deepened (negative change) are shown in blue shades. The 2002–2009 bathymetric change data are also presented in terms of percentage of river mile area in Table 3.1-4 and in Figures 3.1-23a-m. Key observations of major overall bathymetric changes from 2002 to 2009 are listed below:

- Nearly three-quarters of the surveyed area (69 percent) shows elevation changes of less than 1 ft (30 cm) in either positive or negative directions.
- Overall, shoaling is the dominant change observed, with 26 percent of the riverbed surveyed showing net accretion exceeding 1 ft (30 cm), whereas net erosion exceeding 1 ft is noted in only 5 percent of the riverbed overall. However, this includes dredged areas, so the percentage of the riverbed eroding over this time frame due to natural forces is somewhat less than 5 percent.
- Wide areas of deposition occur in the channel and along channel margins in the broader sections of the river (RM 1.5 to 3 [eastern margin], RM 4 to 5, and RM 7 to 10). These areas are known to be long-term sediment accumulation areas based on historical dredging records.
- Signs of in-filling are apparent in formerly dredged borrow areas (e.g., RM 5.2, RM 9 to 10, and RM 10.5 to 11.8).
- Across all eastern nearshore zones, areas of no change accounted for between 7 percent (RM 2–3) and 43 percent (RM 6–7) of each river mile. Percentages of area shoaling ranged from 5 percent (between the end of the navigation channel and RM 11.8) to 90 percent (RM 2–3). Percentages of area deepening ranged from 4 percent (RM 2–3) to 68 percent (RM 10–11).
- In the western nearshore zones, areas of no change make up between 7 percent (RM 0–1) and 54 percent (RM 1–2) of each river mile area, while shoaling areas make up less than 1 percent (RM 0–1) to 85 percent (RM 10-11) and deepening areas make up between 7 percent (RM 10–11) and 92 percent (RM 0–1) of each river mile area.
- In some places, bedforms (e.g., between RM 5 and 6, and RM 11 and 12) can be seen in the navigation channel (alternating high and low spots).
- Throughout the navigation channel, areas of no change account for 12 percent (RM 2–3 and RM 9–10) to 52 percent (RM 6–7) of the river mile segments. Shoaling percentages range from 8 percent (RM 0–1) to 83 percent (RM 2–3), and deepening percentages range from 2 percent (RM 3–4) to 60 percent (RM 0–1).
- The reaches between RM 5 and 7 and RM 10 and 11.8, where the river is relatively narrow, show areas of small-scale net erosion, as does the western off-channel area from RM 0 to 3 (outside bend of the lower Willamette River as it turns toward the Columbia).
- Many deepening areas are closely associated with berthing areas, slips, and pier structures (e.g., Terminal 4 riverfront dock, Portland Shipyard, Willbridge Terminal), likely the result of anthropogenic factors, such as prop wash from ships and dredging. Since 1997 dredging has occurred at Port of Portland Terminals 2, 4, and 5; the Willbridge Terminal; the CLD Pacific Grain Irving Elevator; the Glacier NW dock; the former Goldendale Aluminum dock; the International Terminals; the BP West Coast Products Terminal 22; the Vigor

Industrial dock; the City Fire Bureau Station 6 dock; the Portland Cement Terminal; and the Ash Grove Cement Rivergate Lime Plant.

#### 3.1.5.2.3 Erodibility

Sediment erosion rates and critical erosion shear stress values for lower Willamette River sediments were measured directly as part of the data collection effort conducted by the LWG in the spring of 2006 (Integral 2006e). This study involved the collection of 17 cores from locations throughout the study area selected to represent a range of bottom conditions in terms of sediment texture and local hydrodynamic conditions. These data are discussed here for their empirical value as a measure of riverbed erodibility of surface sediments throughout the study area in late March 2006.

The sediment cores were subjected to various flows using a Sedflume system to produce a range of shear stresses (a force applied parallel or tangentially to a surface; from 0.1 Newtons [N]/$m^2$ to 10 N/$m^2$) to the sediment surface. Resulting critical erosion flow velocities and erosion rates were measured at approximately 5-cm intervals to depths of approximately 25 cm. Physical properties of bulk density and grain-size distributions were also analyzed at approximately 5-cm intervals. Erosion rates per shear stress applied varied depending on sediment grain size, bulk density, and sediment depth. A summary of the number of applications per shear stress value and the range of observed erosion rates (in cm/s, depth of sediment eroded per unit time) on all Sedflume cores is presented in the Table 3.1-5.

Critical erosion velocity shear stress values[8] (Sea Engineering 2006) were calculated at approximately 5-cm intervals. Median grain size (d50) values for the sediment intervals ranged from 9.7 µm (medium silt) to 401 µm (medium sand), and critical shear stresses ($T_{cr}$) were calculated to range from 0.06 N/$m^2$ to 1.28 N/$m^2$. These data from the Sedflume cores, summarized by core depth interval, are tabulated in Table 3.1-6.

The Phase 1 hydrodynamic model (WEST and Integral 2005) was also used to predict bed shear stresses that would occur in the lower Willamette River under typical low-flow (e.g., 40,000 cfs) and relatively infrequent high-flow (e.g., 160,000 cfs) conditions.[9] Map 3.1-7 shows modeled bed shear under these low- and high-flow conditions. Under the low-flow conditions, bed shear values are predicted to remain below 0.4 N/$m^2$ throughout most of the channel and below 0.1 N/$m^2$ in the nearshore areas. Slightly higher shear stresses (up to 0.7 N/$m^2$) are predicted for the channel near RM 11 and for the head of Multnomah Channel. As a first-order approximation, these data indicate that significant sediment bed movement or resuspension due to natural

[8] Critical erosion velocity shear stress is defined in the Sedflume method (SEA Engineering 2006) as the shear stress at which erosion occurs at $10^{-4}$ cm/s.

[9] Mean daily flows of approximately 160,000 cfs or more were recorded on 119 days (0.9 percent) over the 30-year period of record and on 14 days (0.5 percent) over the RI water years 2001 through March 31, 2008. Mean daily flows of 40,000 cfs or less were recorded on 9,374 days (74 percent) over the period of record and on 2,031 days (77 percent) over the RI water years 2001 through March 31, 2008.

hydrodynamic forces does not occur under the typical flow conditions that take place over much of the year (i.e., less than 50,000 cfs) in the lower Willamette River.

Under the relatively rare high-flow conditions, the predicted bed shear values remain low in most nearshore areas, slips, and embayments but are much higher, as well as more variable, in the channel. The predicted bed shear values in the main channel range from 0.614 $N/m^2$ between RM 2 and 2.3 to the maximum value of 19.7 $N/m^2$, which occurs in the channel at approximately RM 10.3. The highest values (>5.0 $N/m^2$) occur in both the nearshore and channel areas in the more constricted reaches (e.g., between RM 10 and 11, and again between RM 5 and 7; Map 3.1-7). The predicted high-flow bed shear values in the channel approach or exceed the highest critical shear stress calculated from the Sedflume study (1.28 $N/m^2$) throughout much of the study area, indicating that sediment transport is likely to occur throughout much of the channel during this flow condition.

#### 3.1.5.2.4 Suspended Sediment

Suspended sediment loads are an important component to understanding sediment transport in the lower Willamette River. Sediment in motion can be classified according to its transport mechanism as either bed load (particles that are rolling, sliding, or saltating along the bed) or suspended load (particles moving in the water column) (Biedenharn et al. 2006). The hydrodynamic conditions which generate bottom shear forces that are predicted to result in the resuspension of study area bedded sediments (and so increase suspended load) based on site-specific erosion measurements are described in Section 3.1.5.2.3.

Biedenharn et al (2006) note that an alternative approach of classifying sediment in a river system is based on the source of the sediment within the catchment. In this classification scheme, typically used in regional sediment management programs, the total sediment load in a system is made up of bed-material load, which is sediment in transport that is derived from and found in appreciable quantities in the channel bed, and wash load, which is sediment in transport that is derived from sources other than the bed.

Wash load is typically produced through land erosion and can be associated with precipitation/storm events (including CSO and other lateral stormwater inputs). Wash load is composed of grain sizes finer than those found in the bed material. Wash load readily remains in suspension, and is generally washed out of the river without being deposited.

##### *Total Suspended Solids Data Sets*

TSS data have been collected by the LWG both as part of the surface water data collection effort to understand distributions and patterns of chemical concentrations, and to support the hydrodynamic model and understand the relationship between river hydrodynamics and the suspended sediment (i.e., suspended load). Surface water samples were collected by the LWG and analyzed for TSS (reported in mg/L) during

Rounds 2A and 3A. The surface water data set also contains TSS data collected by NW Natural (see Appendix A1: WLCGSG07) and the City of Portland (see Appendix A1: WLC1200Z). The NW Natural data were collected as part of an independent investigation conducted in 2007 that included the collection of surface water samples, and the City of Portland data were collected as part of a long-term surface water monitoring program conducted at multiple points along the river. The TSS data sets are described in Tables 3.1-7 and 3.1-8. Figures 3.1-24a-h and 3.1-25a-h present the discharge hydrograph, precipitation, sampling events, and TSS results from the period of October 1, 2000 through April 2008. The TSS results shown in Figures 3.1-25a-h are broken out into upriver and study area sampling locations. (The City of Portland's RM 1.1 sampling location is also plotted in the study area data series on these figures.)

***Relationships between Total Suspended Solids and River Discharge***

The TSS data, associated daily mean discharge values on the day of sampling, and precipitation recorded on the day of sampling and the day prior to sampling, are presented in Table 3.1-9. A scatterplot of all the TSS results and their corresponding discharge values is shown in Figure 3.1-26. The data indicate that while TSS concentrations generally increase as discharge increases, there is significant scatter in the data, especially at the lower end of the discharge range. As discussed in Section 3.1.5.2.3, significant sediment bed movement or resuspension due to natural hydrodynamic forces does not occur under flows of less than 50,000 cfs in the lower Willamette River. At lower flow rates, a variety of natural and anthropogenic factors may influence TSS concentrations, including inputs of erodible material in response to storm events occurring locally or farther up the watershed, outfall discharges, etc. (i.e., wash load), as well as anthropogenic factors, such as bedded sediment resuspension due to prop wash.

The data were examined to evaluate the possible role of precipitation on the observed variability of TSS concentrations at lower flow rates. TSS results possibly influenced by precipitation events were identified based on rainfall amounts recorded on the day the TSS samples were collected and the day prior (Table 3.1-9). TSS samples associated with rainfall totals of 0.2 inch or more summed over those two days were flagged as potentially influenced by rainfall. Plots of these data sets against discharge, separated by location into upriver and study area (plus the City of Portland's RM 1.1 station), are shown in Figures 3.1-27 and 3.1-28.

Statistical tests were performed to compare the rainfall-influenced and non-rainfall-influenced TSS data sets; these were run separately for high (>50,000 cfs) and low (<50,000 cfs) discharge values. Because the TSS data are not normally distributed, nonparametric tests were used. The Mann-Whitney test (also known as the Wilcoxon rank-sum test) was used to compare the central tendencies (medians) of the two data sets, and the Kolmogorov-Smirnov test was used to compare the shapes and locations of their distributions. These tests determine the probability that the two data sets were derived from the same population. In all cases, a 95 percent confidence interval was used to determine statistical significance.

During periods of high discharge, the Mann-Whitney test results indicate that there is no statistically significant difference between the medians of the precipitation-influenced and non-precipitation-influenced data sets ($p$=0.2538). Similarly, the Kolmogorov-Smirnov test suggests that the distance between the empirical cumulative distribution functions is not statistically significant ($p$=0.1177). Conversely, during periods of low discharge, the distinction between precipitation-influenced and non-precipitation-influenced TSS values is significant. The Mann-Whitney and Kolmogorov-Smirnov tests both result in $p$-values that are <0.01. As such, we can conclude that the effect of precipitation on TSS values is statistically significant only when flow rates are low. The correlation between TSS and discharge in the combined upriver and study area data sets was evaluated using Kendall's tau ($\tau$) coefficient. This non-parametric test accounts for ties and for censored data (i.e., non-detects). Tau is a normalized representation of the number of concordant pairs (TSS concentration and discharge increase or decrease together) to discordant pairs (TSS concentration decreases as discharge increases, or vice versa). A value of 1 would indicate that TSS and discharge always move in the same direction (increasing and decreasing together), a value of −1 would imply a perfect inverse relationship (one variable always decreases when the other increases), and a value of 0 would signify no relationship between the variables. This test was run on separately on high and low discharge data sets, and iterations were produced for all data, precipitation-influenced data only, and non-precipitation-influenced data only.

Under high discharge conditions (>50,000 cfs), $\tau$ for the data set is 0.52 ($p$<<0.01), indicating a significant positive correlation between TSS and discharge. This correlation at high flow rates is stronger for non-precipitation-influenced data ($\tau$=0.61) than precipitation-influenced data ($\tau$=0.44). The TSS data associated with lower flow rates (i.e., less than 50,000 cfs) show a much weaker positive correlation ($\tau$=0.09) than the higher flow rate data. This low discharge correlation is slightly stronger when only the non-precipitation-influenced TSS data are considered ($\tau$=0.13), but there is no statistically significant correlation when using only the precipitation-influenced data. This indicates that TSS and discharge are much more strongly correlated during periods of high discharge than during periods of low discharge. In both cases (high and low discharge), non-precipitation-influenced TSS data are much more strongly correlated with discharge than precipitation-influenced TSS data.

Overall, these evaluations indicate that a positive correlation exists between TSS concentrations and flow rate in the lower Willamette River except for instances of low discharge paired with heavy rainfall. The relationship is significantly stronger among the data collected at flow rates above 50,000 cfs, when natural resuspension of bed sediment is expected to occur. Below 50,000 cfs, TSS concentrations are only weakly correlated with flow. Additionally, TSS data associated with precipitation events are less correlated with river flow than non-precipitation-influenced TSS data, which suggests that runoff inputs may introduce additional variability into the TSS-discharge relationship. This result is echoed by the Mann-Whitney and Kolmogorov-Smirnov test results for low discharge scenarios, which show that TSS concentrations differ when comparing precipitation-influenced and non-precipitation-influenced data. The role of precipitation in controlling TSS was not, however, significant during periods of high discharge, suggesting that the natural resuspension of bed sediment is a more dominant factor than runoff in driving TSS values.

***Suspended Particle Grain Size***

*In situ* suspended particle sizes were measured at HMV01 through HMV05 (RM 2, 6.3, 11, and 18) in early April 2006 using a LISST as part of the physical system data collection (Integral 2006n). Particle size was measured in 0.5-m increments through the water column. The median grain-size measurements with depth at each station are plotted in Figure 3.1-29, and a summary of the grain-size ranges measured is tabulated in Table 3.1-10. As indicated by the data, particles primarily in the silt and fine-to-medium sand size ranges were in suspension when river flows were less than 30,000 cfs. The coarsest median grain sizes were found upstream of the harbor at station HMV05 (RM 18) where the river is relatively narrow.

#### 3.1.5.2.5 Hydrodynamic and Sediment Transport

A numerical HST modeling effort was conducted as part of the Portland Harbor RI to complement the empirical observations and gain a further understanding of physical system dynamics. A primary objective of this modeling for the RI was to predict the potential impact of extreme (flood) events on Site sediment stability, particularly the potential for buried contaminated sediments to be re-exposed. Other objectives include understanding the complex hydrodynamics (i.e., the movement of surface water) of the lower Willamette River system (e.g., see Section 3.1.3)

Development of the HST model began in 2003, and the model has been through several development phases with USEPA coordination and input. The RI HST modeling work is detailed in a series of documents (Integral 2006e; Integral and WEST 2006; WEST 2004, 2005; WEST and Integral 2005, 2006), and the final revised RI Phase 2 HST modeling report has been provided under separate cover (WEST and Tetra Tech 2009). Key aspects of the model, important developmental milestones, site-specific data collected to improve model performance, and major model sediment transport outputs are summarized in the sections that follow.

The HST model uses the Environmental Fluid Dynamics Code (EFDC). EFDC is a public domain, multifunctional, surface water modeling system, which can include hydrodynamic, sediment-transport, and eutrophication components. EFDC has been used for more than 80 modeling studies of rivers, lakes, estuaries, coastal regions, and wetlands in the United States and abroad.

The EFDC model's sediment-transport component is capable of simulating the transport of multiple size classes of cohesive and non-cohesive sediment (Tetra Tech 2002). A sediment processes function library allows the model user to choose from a wide range of currently accepted parameterizations for settling, deposition, resuspension, and bedload transport. The sediment bed is represented by multiple layers and includes a number of armoring representations for noncohesive sediment and a mixed bed material finite-strain consolidation formulation for dynamic prediction of bed-layer thickness, void ratio, and pore water advection. The sediment-transport component can operate in a morphological mode, with full coupling between the hydrodynamic components, to represent dynamic evolution of bed topography. Water column/bed exchange processes include particulate deposition and resuspension, pore water entrainment, and pore water advection and diffusion.

### *Phase 1 Modeling*

In accordance with the Modeling Approach Technical Memorandum (WEST 2004), Phase 1 of the RI modeling, including model setup, an analysis of model sensitivity, and initial model calibration and validation runs for both hydrodynamics and sediment transport were conducted (WEST and Integral 2005) and revised (WEST 2005). The Phase 1 revisions incorporated refinements identified in USEPA's review of the initial Phase 1 results, as well as site-specific sediment data collected in Round 2 of the Portland Harbor RI/FS in the latter half of 2004. The primary objective of the Phase 1 modeling was to determine if a two-dimensional (2-D) model would be adequate for the site, in terms of addressing model objectives. Due to the relatively small tidal influence in the lower Willamette River and the general lack of a significant density structure (i.e., density gradients with depth in the water column that significantly influence circulation; WEST 2004), Phase 1 concluded that a 2-D model was adequate. The secondary Phase 1 modeling objective was to gain an understanding of the site's physical processes and the impact of various model parameters on the model predictions. Based on the model sensitivity and performance analyses, additional potential site-specific data needs were identified.

Overall, the Phase 1 model effectively simulated the hydrodynamics. However, bed elevation changes were not well captured by the model at the target accuracy levels. As a result, a number of site-specific data needs related to improving the sediment transport performance of the model were identified and collected in 2006.

In general, these data needs were associated with the behavior of cohesive sediments in the system (e.g., settling velocities and erodibility).

### *Phase 2 Modeling*

In Phase 2, the HST model was revised and recalibrated using the site-specific modeling data collected in 2006. The revised model computation domain extends from the confluence with the Columbia River (RM 0) to the confluence with the Clackamas River (RM 24.1), and the Multnomah Channel to its confluence with the Columbia River near St. Helens, Oregon (WEST and Integral 2006). The upstream boundary of the Phase 2 HST model was shifted to approximately 2.4 miles downstream of the Willamette Falls (RM 26.6), which was the upstream boundary in the Phase 1 model (WEST and Integral 2006).

The Phase 2 model focused on identifying a combination of the reference critical shear stress for deposition, reference resuspension rate, reference critical shear stress for resuspension, and reference void ratio to minimize the differences (both statistically and graphically) between the measured and simulated bed change over the calibration period.

Compared to the revised Phase 1 results, the Phase 2 model showed some improvement in the agreement between simulated and measured bed elevations by incorporating site-specific data. The model did a better job in the deeper portions of the river than the nearshore areas. This is expected as sediment transport in nearshore areas might also be affected by other factors (e.g., local flow features near structures and prop wash) that are not explicitly represented in the model. The revised Phase 2 calibration results are detailed in the Revised Phase 2 Recalibration Results for the Hydrodynamic Sedimentation Model (WEST and Tetra Tech 2009).

### *HST Model – Flood Simulation*

In 2009, the LWG fully modified the sediment transport portion of the HST model. The primary HST model application for the RI is to examine the potential for contaminated subsurface sediment re-exposure due to a major flood event in the lower Willamette River.

The 2009 HST model was used to predict the bed elevation changes (i.e., the areas and magnitude of erosion and deposition in the study area) that would result from five different high-flow scenarios. A range of high-flow simulations were run because bed response can be a function of the long-term hydrographic conditions that exist leading up to the flood event. Figure 3.1-30 shows the simulated hydrograph for the flood event that produced the largest overall riverbed elevation changes (note that this hydrograph includes a simulation of the 1996 flood following 5 years of high flow). Map 3.1-8a shows the net bed elevation changes, both erosion and accretion, following the simulated high-flow event. For comparison, Map 3.1-8b shows the maximum erosion levels predicted for each model cell during this simulated high-flow event; this map is a mosaic of maximum erosion per cell at any point during the simulation, and so shows the maximum extent of erosion for each cell regardless of backfilling that might occur on the falling limb of the hydrograph. The flood event maximum erosion map (Map 3.1-8b) shows that 38 percent of model cells in the study area undergo erosion at any point during the simulated flood; most of these cells (85 percent) undergo erosion of 30 cm (1 ft) or less. Overall, 6 percent of study area cells undergo maximum erosion greater than 30 cm (up to 192 cm or ~6.4 ft) and, therefore, are predicted to exceed the 30-cm project-defined surface sediment layer during the modeled flood event. This erosion of deeper, “subsurface” sediments, indicated by the three darkest shades of blue cells is localized in three regions of the study area (Map 3.1-8b):

- The navigation channel from RM 10 to 11.8, particularly upstream of RM 10.7
- The navigation channel from about RM 5.2 to 6.8 and adjacent eastern nearshore zone cells between RM 6.1 and 6.7

- An isolated cell in the eastern nearshore at RM 3.1.

These more deeply eroded areas correspond to areas that are predominantly sandy in texture, which tend to be erosional under high flow conditions.

Beyond these areas, the HST flood simulation predicts that most areas of erosion will occur within the navigation channel. Much of the navigation channel will experience erosion on the order of 15 to 30 cm. Most nearshore or off-channel (e.g., Swan Island Lagoon) areas are not predicted to erode. Similarly, several portions of the navigation channel (i.e., RM 1.7 to 3.0), most of RM 4 to 5, and the western half of the channel from RM 7.3 to 9.2, also are not predicted to be erosional.

It should be noted that anthropogenic forces (e.g., boat wakes, prop wash, etc.) and wave action that typically occur in the nearshore areas and may disturb sediments are not accounted for in the RI HST model. Thus, the predictability of the model to determine the exposure of subsurface contamination is limited in these nearshore environments where anthropogenic forces dominate.

#### 3.1.5.2.6 Sediment Transport Regimes

In the deeper, offshore areas of the harbor (i.e., the navigation channel and adjacent areas in the main stem of the lower Willamette River deeper than about –20 ft NAVD88, see Map 3.1-9), the movement of water and sediment appears to be controlled in large part by the physical shape of the river, both the cross-sectional area and anthropogenic alterations such as borrow pits, dredged areas, and structures (e.g., bridge footings). In the off-channel, nearshore areas, especially areas less than –20 ft (NAVD88) in depth, the sediment dynamics are complicated by local riverbank morphology, seasonal changes in water levels, bank treatments, and other anthropogenic factors such as prop wash. Map 3.1-10 shows several cross-sectional channel profiles from RM 1 to 13 and illustrates the variability of the river morphology throughout the study area. The cross-sectional profiles include both the 2002 (blue) and 2009 (red) bathymetry and show where deposition and erosion have occurred. Select sediment-profile images from the 2001 SPI survey are included on Map 3.1-10 to show how river bed surface textures and sediment shear strength (as indicated by the depth of the SPI camera prism penetration; SEA 2002b) vary in accordance with the river's cross-sectional area and depositional setting. Finally, the plan view 2002 to 2009 bathymetric change data (Map 3.1-6) is included as the background layer on Map 3.1-10 to provide the reader with a comparison of variation in cross sections with bathymetric elevation changes.

Map 3.1-11 shows predicted (HST model) bottom shear forces in the lower Willamette River from RM 24 (the upstream end of the 2009 HST model domain) to the Columbia River (RM 0) under a relatively high flow regime (160,000 cfs); this was the flow condition observed in the lower Willamette River in late January 2004 when the Columbia River stage was relatively low. The combination of high flows in the Willamette River coupled with a low Columbia River stage is expected to produce the greatest bottom shear forces in the lower Willamette River. With the exception of the area from approximately RM 15 to 17, Map 3.1-11 shows that narrower upriver areas from RM 12 to 24 experience much higher near-bottom shear forces than occur within Portland Harbor (RM 12 to the Columbia River at RM 0).

Table 3.1-11 summarizes some of the key hydrodynamic and sediment transport characteristics of the lower Willamette River by major reaches with a focus on the distinct variations observed in subsections of the study area. The hydrodynamic character and sediment transport regimes of the lower Willamette River may be broadly described in terms of the 10 reaches discussed in the following subsections.

### *Upriver Reaches*

There are two reaches upstream of the study area that are summarized in Table 3.1-11 and described below:

**Upriver (RM 26 to 15.3)**

The upriver segment includes the stretch of the river from Willamette Falls to the upstream end of Ross Island (approximately RM 26 to RM 15.3). Here the river is relatively narrow and flows through suburban areas under largely natural conditions, with the exception of the control structure (USACE Locks) at the Willamette Falls (approximately RM 26). Much of the river bottom consists of exposed basalt bedrock (GeoSea Consulting 2001). Bed shear stresses through this area are generally high (averaging 5.8 $N/m^2$), with the highest shear stresses occurring in the bend between RM 23 and 24 (>40 $N/m^2$; Map 3.1-11). Sustained current speeds in this reach appear to prevent all but the coarsest material from settling in the main stem of the river. Some low to moderate shear stresses occur in the smaller bifurcated channels, embayments, and sheltered nearshore areas. The most extensive relatively low-energy area occurs at the downstream end of this reach from approximately RM 15 to 17 and includes the river channel that runs behind (east of) Ross Island; predicted shear stresses here range from 0.4 to 4 $N/m^2$.

**Downtown Reach (RM 15.3 to 11.8)**

The downtown segment of the lower Willamette River extends from the upstream end of Ross Island (RM 15.3) to the upstream end of the study area at RM 11.8. Like the upriver reach, this is also a relatively high-energy segment of the river, where the main channel of the river is narrow (average cross-sectional area estimated at 34,000 $ft^2$) with steep channel margins that are largely constrained by upland bulkheads along both riverbanks. The deepest areas of the channel are found on the outer edges of bends in the river below Ross Island, and in the dominant bifurcation channel west of Ross Island. Relatively high bed shear stresses (averaging 3.4 $N/m^2$) occur in the main portions of the channel, while lower shear stresses occur in the channel east of Ross Island and in shallower nearshore areas associated with some bends in the river (Map 3.1-11).

The high-energy environment of the main channel is evidenced by the observed bedded sediment texture, which consists primarily of gravels and sands (SEA 2002a). Localized areas of exposed bedrock occur, particularly near bridges where scouring appears related to footing structures (GeoSea Consulting 2001). Fine-grained deposits are observed in some nearshore areas sheltered from the main flow of the river (SEA 2002b). The SPI image from RM 12.4 (Map 3.1-10) illustrates the high energy setting of this area, showing an apparently small-scale transgressive, well-sorted, fine to medium, brown sand bedform overlying and advancing over a poorly sorted gray, silty, fine sand (SEA 2002b). The 2002 to 2009 bathymetric change data (Map 3.1-6) show limited sediment accretion throughout this reach, particularly downstream of RM 14, where areas showing no change and small-scale deepening (≤1 ft) are dominant (Integral 2004a).

### *RI Study Area*

The study area extends from RM 1.9 to 11.8 and the lower Willamette River −40 ft CRD authorized federal navigation channel nearly overlaps it, extending upstream from the Columbia River to RM 11.7 (Broadway Bridge).

Map 3.1-12 juxtaposes on a single panel the contoured surface grain-size patterns, the measured bathymetric change from 2002 to 2009, and the HST-predicted net riverbed elevation changes following a major flood event for the study area. The overlap of certain elements of these features across the study area, as well as the physical and hydrodynamic conditions observed and measured within the study area, helps support the discussions provided below.

#### RM 11.8 to 10

The cross-sectional area of the river begins to increase in this segment as the river broadens in a downstream direction, but the hydrodynamic energy in this segment of the study area remains relatively high (Maps 3.1-10 and 3.1-11) and comparable to the upriver reaches (e.g., see high-flow bed shear values in Table 3.1-11). This is evidenced by the high potential bed shear stresses, particularly in the eastern portion of the main channel where the channel bank is steep (Map 3.1-9), and by the observed bed sediment texture, which is dominated by sand (Map 3.1-12). The lower bed shear stresses predicted to occur by the RI HST model outside the channel, along the eastern bank at RM 11.5 at the Goldendale Aluminum facility (Map 3.1-11), is supported by the historical dredging that has been required to maintain that facility's docking berth (CH2M Hill 2001a).

The off-channel, nearshore areas of this reach are narrow, and show a nearly equal proportion of small-scale deepening, shoaling, and no-change areas (Integral 2004a). The channel through this reach has generally undergone minor net deepening over the study period (on the order of 30 cm [1 ft], or less), though small areas have deepened more substantially. Deposition on the order of several feet has occurred in the deep areas of previously dredged holes (borrow pits) on the western side of the channel (Map 3.1-11). These are the farthest-upstream areas of net deposition greater than 1 ft in the lower Willamette River surveyed bathymetrically (i.e., from the Columbia River to the upper end of Ross Island) as part of the Portland Harbor RI/FS. Sand waves are evident migrating along the western portion of the channel between RM 11 and 11.7 (Map 3.1-6).

The 2009 HST model flood scenario predicts areas of deep (>100 cm) erosion occurring in some central portions of the navigation channel between RM 10.7 and 11.6 in this reach (Map 3.1-8b), but deposition reduces the extent of net deepening, or even dominates, in other portions of the channel, and dominates in nearly all off-channel areas (Map 3.1-8a). However, the observed changes in bathymetry (Map 3.1-6) contradict the model's predictions, showing the limited applicability of the model to accurately predict erosion and deposition in this reach of the river.

**RM 10 to 9.2**

The river becomes predominantly depositional as it widens significantly around RM 10. The increase in cross-sectional area reduces flow velocities, as reflected by the lower predicted bed shear stresses (Table 3.1-11) from the 2009 HST model, particularly along the broad western flank of the channel (Map 3.1-6), and the widespread sediment accumulation predicted by the 2009 HST model in this area (Map 3.1-8a). The observed changes in bathymetry (Map 3.1-6) show that there is more widespread sediment accumulation than predicted by the model, especially on the west bank of the river and extending into the navigational channel. An extensive shoaling on the order of 60 to 150 cm (~2 to 5 ft) in extent is evident along the broad western flank of the channel here.

Observed bed sediment textures reflect the cross-channel energy differences, with coarser-grained deposits dominating the eastern portion of the riverbed and finer-grained deposits occurring along the western portion (Map 3.1-3). The SPI image taken at RM 9.3 (station STA66F; Map 3.1-10) shows the riverbed to be composed of a thin silt layer overlying well-sorted medium sand, evidence that this eastern nearshore location undergoes alternating periods of sediment transport, when the fines are winnowed from the sands, followed by quiescent periods that allow deposition of the silt (SEA 2002b).

The 2009 HST model predicts erosion to depths of approximately 30 cm in the navigation channel in this reach during the flood event (Map 3.1-8b), but net results show deposition dominating in the nearshore areas and reducing or eliminating the net erosion in some parts of the channel (Map 3.1-8a). However, the observed changes in bathymetry (Map 3.1-6) show that there is more deposition in the navigational channel and less deposition in the nearshore areas, especially on the east side of the river.

**RM 9.2 to 6.9**

This reach is the broadest segment of the study area with a relatively wide cross-sectional area (Map 3.1-10), estimated at an average of 68,000 $ft^2$, and moderate to low bottom shear stresses (Table 3.1-11). The reach is dominated by fine-grained surface sediments (Map 3.1-3). The depositional nature of the majority of this reach is seen in the areas of shoaling observed in the channel between RM 7.8 and 9.2 and along the eastern (directly downstream of Swan Island) and western channel-edge areas downstream to RM 6.9 (Map 3.1-6). Maintenance dredging has been required historically along the western shoreline of this reach (see Section 3.2.3.1.13). The large off-channel areas in this reach (e.g., Swan Island Lagoon) are characterized by very low bed shear but little or no sediment deposition (Map 3.1-12). Isolated areas of deepening observed in Swan Island Lagoon and at Willbridge Terminal are likely the result of anthropogenic factors such as prop wash and dredging. Dredging of sediments along the Willbridge Terminal piers occurred between winter 2002 and winter 2009 (Map 3.1-6).

**RM 6.9 to 5**

The river again narrows in this reach to an average cross-sectional area of approximately 57,000 $ft^2$ (Map 3.1-10). This stretch of river is a relatively high-energy sediment transport zone with high-flow bed shear rates (4.2 $N/m^2$) that approach the values predicted upstream of RM 10. Predicted maximum bed shear stresses (Map 3.1-11 and Table 3.1-11) indicate that more erosion and less sedimentation is likely to occur.

The high-energy nature of this segment of the river results in predominantly sandy surface sediments (Map 3.1-3). Examples of this are illustrated in the SPI photos in Map 3.1-10. The riverbed surface in the SPI snapshot from RM 6.9 (STA 47C) is composed of fine to medium, brown sand; the tan silt lenses within the sand matrix are evidence of active sediment transport (SEA 2002b). The riverbed seen in the SPI snapshot at RM 5.5 (STA 36B) is composed of poorly to moderately sorted, fine to medium sand, and also appears to be undergoing sediment transport (SEA 2002b).

The 2002 to 2009 bathymetric change (Map 3.1-6) shows that the channel in this reach is a mosaic of no change, small areas of sediment accumulation (mostly associated with channel depressions), and some small-scale scour. Localized areas of exposed bedrock have been noted, particularly on the west side of the river near the St. Johns Bridge. Sand wave migration is evident along the central portion of the channel between RM 5 and 6. Outside the channel, the narrow eastern nearshore area and the nearshore western area from RM 6.5 to 6.9 is dominated by scour, whereas the narrow western nearshore zone shows sediment accumulation between RM 5 and 6.5.

The 2009 HST modeled flood scenario predicts relatively deep (61 to 152 cm [2 to 5 ft]) erosion occurring in portions of the thalweg (i.e., the deepest area of the channel) and, to a lesser extent (less than 61 cm), in adjacent channel margin areas (Map 3.1-8b). Some of the deeper portions of the navigation channel downstream of RM 5.5 and some off-channel areas predict net deposition following the high-energy event (Map 3.1-8a). This includes the outer portions of Willamette Cove and narrow swaths along the eastern and western nearshore areas from RM 5 to 5.5 and from RM 5.8 to 6.1.

**RM 5 to 3**

The river widens again below RM 5 to an average cross-sectional area of 65,000 $ft^2$ (Map 3.1-10). The bathymetry is dominated by a deep (up to –70 ft NAVD88) dredged area in the eastern half of the channel between RM 4 and 5, which gradually shoals to the typical -40 ft depth CRD downstream of the International Terminal Slip (RM 3.6E). The time-series bathymetry indicates that the majority of the riverbed in the main channel undergoes minor net shoaling (30 cm or less) with swaths of more significant sediment accumulation along east and west channel edges and nearshore areas, especially between RM 4 and 5 (Map 3.1-6). The isolated areas of scour that are evident in some nearshore areas are likely due to anthropogenic factors; some dredging is also evident at the Port's Terminal 4 slips located between RM 4 and 5 on the eastern shore of the river. The hydrodynamic model predicts low to moderate bed shear stresses, with relatively lower bed shear in the deeper upstream portion of this river segment and along the channel margins (Map 3.1-11 and Table 3.1-11).

Surface sediments are dominated by silts (60–80 percent fines) with some exceptions. The International Terminal Slip is mostly sand with very little fines (0–40 percent fines), most likely due to anthropogenic factors (e.g., prop wash) (Map 3.1-3). The mid-channel at RM 4 and a cross-channel swath at RM 3.2 leading into Multnomah Channel are also dominated by sandy surface sediments.

The 2009 HST modeled flood scenario predicts erosion on the order of 30 cm (1 ft) in portions of the navigation channel and in the channel margin and nearshore areas downstream of RM 3.4 (Map 3.1-8b). Up to 61 cm of erosion is predicted for an isolated cell in the eastern nearshore at RM 3.1. However, deposition during the flood event is predicted to reduce or eliminate the net erosion observed in many cells in this reach (Map 3.1-8a). Model results show net deposition exceeding 30 cm in much of the channel and nearshore area from RM 4 to 5, and to a lesser extent in the RM 3 to 4 segment, including small depositional zones along the western nearshore area just upstream of Multnomah Channel and just upstream of RM 3 in the eastern nearshore zone (this is a predicted nearshore shoal that continues to RM 1.5).

**RM 3 to 1.9**

A significant fraction (up to 50 percent) of the downstream lower Willamette River flow moves down the Multnomah Channel; the reduced discharge volume of the lower Willamette River downstream of Multnomah Channel results in markedly reduced bottom shear bed values (Maps 3.1-7 and 3.1-11). In addition, the main stem of the lower Willamette River continues to widen in this reach as it bends to the northeast, to an average cross-sectional area of approximately 68,000 $ft^2$ (Map 3.1-10). Maximum bed shear values are approximately half what they were just upriver from Multnomah Channel (Table 3.1-11) and are particularly low on the inside curve of the bend (Map 3.1-11). This is the lowest energy main channel reach in the study area. This is reflected in the observed surface sediment texture, which is predominantly fine-grained, and in the shoaling observed in the channel and east of the channel throughout this reach between 2002 and 2009. The area to the west of the channel boundary in this reach shows little net change over this time period. The 2009 HST modeled flood scenario predicts very little erosion, with deposition dominating the area virtually from bank to bank (Maps 3.1-8a,b). This is inconsistent with the time-series bathymetry (Map 3.1-6), which shows that deposition is occurring at the inside bend of the river on the eastern shore and is in dynamic equilibrium (i.e., neither deposition nor erosional) at the outside bend of the river on the western shore.

### *Downstream Reaches*

There are two reaches downstream of the study area that are briefly described below:

#### Downstream Reach (RM 1.9 to 0)

The remaining river segment downstream of the study area extends to the Willamette's confluence with the Columbia River. Bed-shear stresses are low to moderate (Table 3.1-11), increasing from about RM 1.6 downstream as the river narrows and becomes more dynamic as it reaches the Columbia River (Map 3.1-11). Net shoaling (greater than 60 cm [2 ft]) was observed along the eastern channel edge and east of the channel to around RM 1.5 (Map 3.1-6). This is a continuation of the pattern seen upstream of RM 1.9; this is the furthest downstream extent of significant sediment deposition in the lower Willamette River channel. Net deepening (60 cm or less) occurred from 2002 to 2009 in a narrow strip outside the channel along the western nearshore area, particularly in the final 1 mile of this reach, possibly representing natural channel migration along the outside bend of the river.

Surface sediments transition from silts to sands at approximately RM 1.5 and remain predominantly coarse-grained to the Columbia. The 2009 HST modeled flood scenario predicts erosion to occur throughout most of this area, generally up to 30 cm, but up to 61 and 152 cm in areas downstream of RM 1 (Map 3.1-8b). Some net deposition is predicted to occur in this reach in the center of the navigation channel just upstream of RM 1 and along the eastern shoreline (Map 3.1-8a). This is consistent with the observations from the time-series bathymetry.

#### Multnomah Channel (Lower Willamette River to the Sauvie Island Bridge)

Multnomah Channel between the lower Willamette River and Sauvie Island Bridge (~0.5 mile downstream) sees relatively high flows and bottom shear forces. The channel is much narrower (~one-third the width) than the main stem of the lower Willamette River, and the flow moving down the channel is constrained by dikes (Map 3.1-9). Sandy sediments dominate the channel and the area immediately adjacent to it in the lower Willamette River (Map 3.1-12). Time-series bathymetric change data is not available for the Multnomah Channel since the bathymetric studies were only conducted for the main channel of the lower Willamette River. The 2009 HST modeled flood scenario includes the entrance and uppermost portions of the Multnomah Channel and indicates little or no change in the riverbed elevations in this area.

### 3.1.6 Surface Features

#### 3.1.6.1 Topography

Elevation in Portland Harbor varies from 0 to 300 ft (0 to 90 m), with buttes as high as 650 ft (200 m). Portland Harbor is a geological depression bordered to the east by the Tualatin Mountains (also known as the West Hills or Southwest Hills of Portland), which are a spur of the Northern Oregon Coast Range and include a portion of the Boring Lava Field (Allen 1975), and to the west by a 120-ft-high natural bluff that runs along the northeast border of the Site (see Map 3.1-1).

The West Hills date from the late Cenozoic era and range up to over 1,000 ft (300 m). Composed mainly of basalt, the mountains were formed by several flows of the Grande Ronde basalt flows that were part of the larger Columbia River basalts. Much of the northern portion is undeveloped land within the 5,000 acres (20 $km^2$) of Forest Park. The landscape, inside and outside the park, is predominantly forested. The slopes of the hills, rising relatively steeply at about 1.5H:1V to 3.5H:1V, are subject to periodic landslides; most slides are small and shallow.

Most of the lowlands on either side of the Willamette River within Portland Harbor are located on a terrace with elevations that range between 30 and 50 ft above sea level, mostly composed of fill material. The lowlands extend for approximately 0.5 to 1 mile from the river before reaching the confining features of the Tualatin Mountains to the east or the 120-ft-high natural bluff that runs along the northeast border of the Site.

#### 3.1.6.2 Bathymetry

An initial bathymetry study was conducted by DEA between December 13, 2001 and January 14, 2002, during the winter period of relatively high water. The primary goal of the survey was to develop an accurate, baseline, riverbed elevation database for this portion of the lower Willamette River. A smaller survey was also conducted by the LWG in February 2007 that focused only in Multnomah Channel.

Three additional major multibeam bathymetric surveys were conducted by the LWG in July–September 2002, May 2003, and February 2004. Another multibeam survey of the lower Willamette River was conducted by NOAA in January 2009. Comparison of these time-series bathymetry survey results with the initial survey allows areas of riverbed that shoaled or scoured to be identified. A discussion of these comparisons is provided in Section 3.1.5.2.2.

The vertical accuracy of the water depth measurements in the bathymetric surveys was specified at less than or equal to 0.5 ft (NAVD88), and the horizontal accuracy was set at less than or equal to 1 m. The data were processed using a 1-m grid size to generate a digital terrain model, and the survey results were plotted in both three-dimensional (3-D) color-graded (i.e., “hillshade”) and contour formats. The most recent survey results (NOAA 2009) are presented in Map 3.1-9.

Map 3.1-9 shows that most of the study area is from –30 to –50 ft CRD (–25 to –45 ft NAVD88) and is dominated by the authorized federal navigation channel, which runs from RM 0 (Columbia River) to RM 11.7 (Broadway Bridge) and extends nearly bank-to-bank from RM 4 to 6 and again from RM 8 to 11.7. Elevations in the federal navigation channel are generally –40 to –50 ft CRD. Except along the western channel edge from RM 8 to 10 where extensive shoaling has occurred, these portions of the study area have very narrow and steeply sloped off-channel areas. Broader off-channel areas with shallow benches (–10 to –30 ft CRD) occur from RM 1 to 4 along the outside curve of the river, including across the head of Multnomah Channel, between RM 6 and 8, and at the head of Swan Island Lagoon. There are a number of off-channel areas, such as Swan Island Lagoon, Willbridge Terminal, Willamette Cove, Terminal 4, and International Slip, that vary widely in depth as a function of their history and current land use (e.g., actively dredged berths). Finally, there are several deep areas in the harbor that extend from –60 to –80 ft CRD. These are historical borrow areas that were dredged to create the adjacent uplands; the two most extensive ones are in the eastern portion of the channel from RM 4.3 to 5 and RM 9.2 to 10. Map 3.1-13 shows the long-term bathymetric changes that occurred in the lower Willamette River between 1888 and 2001. This map was produced by overlaying and subtracting the 2001 bathymetric survey data from 1888/1895 bathymetric data provided by the City of Portland[10] and illustrates the large-scale deepened, diverted, and filled areas.

#### 3.1.6.3 Manmade Structures

##### 3.1.6.3.1 Bridges

There are five bridge structures within the study area: the St. Johns Bridge (RM 5.8) is a suspension bridge that was constructed in 1931, the Burlington Northern Railroad Bridge (RM 6.8) is a swing bridge (i.e., bridge has a swing span, which pivots on its base to allow for the passage of taller ships) that was constructed in 1906, the Fremont Bridge (RM 11.2) is a steel tied arch design that was constructed in 1973, the Broadway Bridge (RM 11.5) is a truss with double-leaf rall-type bascule lift span design that was constructed in 1913, and the Steel Bridge (RM 12.2) is a double-deck swing-span bridge that was constructed first in 1880 (rail only) with an expansion in 1888 (auto addition) and completely replaced in 1912.

##### 3.1.6.3.2 Piers, Marinas, Docks, and Floating Home Moorages

About 525 acres of the lower Willamette River are occupied by piers, marinas, docks, and floating home moorages. The following provides a general discussion of the location of these structures throughout the site. Maps 3.1-14a-f provide more specific location of these structures.

[10] Bathymetric data provided by the City of Portland was based on a GIS digital model developed using the United States Coast & Geodetic Survey 1888 Columbia River chart (Fales Landing to Portland) and USACE 1895 surveys of the Upper Willamette (Sheets 14 and 15).

***Western Shoreline Structures***

- RM 0 (confluence with Columbia River) to RM 3 (Multnomah Channel), Sauvie Island—There are some small personal use boat docks (5), abandoned pilings, and pile dikes.
- RM 3 to 3.2 (Portland General Electric [PGE] Harborton)—There are no in-water structures.
- RM 3.2 to 4.1—There are existing in-water structures include pilings, dolphins, and dock and loading facilities associated with supporting upland uses (barges, tank farms, plywood mill, wood chips).
- RM 4.1 to 4.8—There are no in-water structures.
- RM 4.8 to 11.2—Existing floating facilities include wharfs, pilings and piers for handling cargo, boat construction, tug and barge moorage, and launching facilities.
- RM 11.2 to 12.2—Existing in-water facilities and structures include pilings and piers over water at the McCormick Pier residential complex, Old Albers Mill office, Centennial Mills, and Fremont Place office complex. Floating structures include the McCormick Pier private marina.

***Eastern Shore Structures***

- RM 0 to 0.9 (Columbia Slough), Kelly Point Park—There are no in-water structures.
- RM 0.9 to 5.8—Existing in-water structures include wharfs, piers, bulkheads, and dolphins needed for ship and barge moorage.
- RM 5.8 to 6.8, Cathedral Park—In-water structures include a public boat ramp, fishing pier, and abandoned pilings.
- RM 6.8 to 7.8—There are many deteriorating in-water structures, including piling structures, docks, and miscellaneous man-made structures.
- RM 7.8 to 8.2—There are no in-water structures.
- RM 8.2 to 9.2, Swan Island Lagoon—The east side includes smaller dock structures and floating boathouse. There is a public boat ramp at the southern end of the lagoon (RM 9.2). The western shore is a continuous piling structure used for ship tie-up.
- RM 8.2 to 9.2, west side of Swan Island—There are three dry docks at the head of Swan Island (including the largest floating dry dock in the Pacific Rim—87,000 tons which was removed in 2001), and numerous ship repair berths.
- RM 9.2 to 10—There are no in-water structures.
- RM 10 to 12.2—In-water structures include bulk loading facility, abandoned pilings, concrete foundations, warehouse pilings, and bulkheads. There is also log raft storage in this area.

### 3.1.7 Habitat

The majority of the study area is industrialized, with modified shoreline and nearshore areas. Wharfs and piers extend out toward the channel, and bulkheads and riprap revetments armor portions of the riverbank. Active dredging has produced a uniform channel with little habitat diversity. However, some segments of the study area are more complex, with small embayments, shallow water areas, gently sloped beaches, localized small wood accumulations, and less shoreline development, providing some habitat for a suite of local fauna.

This section describes the general types and quality of aquatic habitat available to ecological species in the lower Willamette River. The habitats for each ecological receptor group are described in greater detail in the BERA (Appendix G).

#### 3.1.7.1 Open-Water Habitat

The lower Willamette River is characterized by a developed navigation channel and shoreline. The river historically had large amounts of off-channel habitat in the form of floodplain lakes such as Ramsey, Doane, and Guild's lakes. After industrialization, only a few shallower backwater sites (e.g., Willamette Cove, Swan Island Lagoon, individual slips), as well as a tributary (Columbia Slough) and a secondary channel (Multnomah Channel) remain (Map 3.1-15). The deep open water provides foraging habitat for fish and wildlife that feed in the water column. Piers and other structures in the open water provide additional habitat for certain species such as smallmouth bass. Shallow-water habitats provide refuge for juvenile salmonids and other fishes, as well as greater foraging opportunities for birds and mammals. Friesen et al. (2004) found that juvenile salmon were present in every month sampled from May 2000 to July 2003. Juvenile salmon were captured more frequently during winter and spring than during other seasons. Coho and steelhead were generally present only during winter and spring.

Historically the lower Willamette River was dominated by shallow water habitat, with approximately 80 percent of the river with depths less than 20 ft CRD. Dredging and alteration of the river channel have reversed these ratios, and the river is now 20 percent shallow water and 80 percent deep (Map 3.1-16; City of Portland 2009a). Shallow-water habitats, such as those preferred by some foraging wildlife (e.g., otter and mink), are now largely limited to the narrow strip between the shoreline and the navigation channel, which generally is vulnerable to disturbance and anthropogenic alteration due to its proximity to shore. Remaining pockets of shallow water habitat include areas such as Willamette Cove, Swan Island Lagoon, International Terminals Slip, Wheeler Bay, Shaver, Balch Creek Cove, Triangle Park, the mouth and channel of Multnomah Channel, and the Sauvie Island shoreline.

There are three types of benthic habitats in the open water of the lower Willamette River:

- Unconsolidated sediments (sands and silts) in the deeper water (greater than approximately 20 ft CRD) of the navigation channel and lower channel slopes
- Unconsolidated sediments (sands and silts) in shallow water depths (less than 20 ft CRD) in gently sloping nearshore areas (e.g., beaches and benches) and on the upper channel slopes
- Developed shoreline (e.g., rock riprap, sheet pile, bulkheads, piers).

In addition, very limited areas of rock and rock outcrop are present in the lower Willamette River. The navigation channel habitat is subject to variable (daily [tidal], seasonal, and annual) hydrodynamic forces, the impacts of navigation, natural sediment deposition, bed load transport/erosion, and periodic navigational dredging. These forces vary spatially through the system, largely as a function of the channel cross-sectional area, resulting in the presence of both relatively stable and unstable sedimentary environments and patchy infaunal and epibenthic communities that are characteristic of the local physical regime. The physical sedimentary regimes are a function of the local riverbank morphologies, and sheltered areas away from anthropogenic disturbance should support well-developed infaunal invertebrate communities that are characteristic of large river systems. Conversely, exposed nearshore areas, particularly around berths, docks, and boat ramps, likely have limited benthic communities due to the greater physical disturbance in these areas. Tidal and seasonal water level variability and nearshore disturbances (e.g., boat wakes) have a much larger effect in shallow water than they do in deeper water. The hard surfaces of the developed shoreline provide habitat for an epibenthic community.

#### 3.1.7.2 Bank and Riparian Habitat

The most common bank types occurring in the study area are riprap, sandy and rocky beach, unclassified fill, and seawall (Map 3.1-17).[11] In 2008, the City of Portland reported that vegetated riprap (25 percent), unclassified fill (21 percent), and beach (23 percent) were the dominant bank types in the North Reach (Broadway Bridge to the Columbia River; City of Portland 2008a). The riprap or rocky bank type is usually fairly steep with no or very narrow adjacent shallow water habitat present. These areas are usually exposed to heavy wave action and strong currents. The sandy bank type with little to no vegetation is characterized by gently sloped beaches (i.e., sand banks are rarely steep). However, this bank type is often adjacent to steep riprapped shorelines or developed uplands that are frequently exposed to heavy wave action and faster moving water. The rocky or sandy bank types with a mix of native and invasive vegetation are common within the study area. These bank types range from gently to steeply sloped beaches and, similar to the sandy bank type without vegetation, are often adjacent to steep uplands, although the uplands are either of sandy or rocky substrate. The rocky or sandy bank types are generally located in areas with less development and

[11] Classifications on Map 3.1-17 are based upon an ODFW 2000–2003 study (Vile and Friesen 2004) and are known to be outdated or incorrect in some locations.

a lack of bank hardening, such as in Swan Island Lagoon, the Multnomah Channel, Kelley Point Park, and Sauvie Island.

The type of riverbank present in the study area is expected to influence fish species occurrence and use of a given area. Riverbanks with large woody debris and riparian vegetation that provides cover and creates small shallow pools will likely be used by juvenile salmonids and other small fish species (Bjornn and Reiser 1991; Sedell and Froggatt 1984). Areas with limited wood accumulations include the beach adjacent to Freightliner Corp., Kelley Point Park, and Mar Com. Friesen et al. (2004) found that in the lower Willamette River, coho preferred beach habitat and rock outcrops and avoided riprap and artificial fill, and the abundance of all species was low at seawall sites.

The riprap and rocky substrate are the preferred habitats of sculpin and smallmouth bass (Farr and Ward 1993; SEA et al. 2003; Wydoski and Whitney 2003). Sculpin are predominately present in the shallow water habitats, and smallmouth bass are present in areas with moderate current. The shallow backwater pools and slow-moving areas of the river provide habitats for juvenile largescale suckers (yearling and subyearling) and peamouth (Wydoski and Whitney 2003). The peamouth remains nearshore during winter months and moves to deeper waters in the summer months. The shallow waters with abundant plants and woody debris available for cover are the preferred habitats for largemouth bass.

Numerous aquatic and shorebird species such as cormorants and spotted sandpipers use the habitats in the lower Willamette River. The upland environment near the lower Willamette River is primarily urban, with fragmented areas of riparian forest, wetlands, and associated upland forests (Map 3.1-18). Historical development and filling of channels and wetlands has left only small strips or isolated pockets of riparian wildlife habitat, with the exception of areas such as Harborton Wetlands, Oaks Bottom, Forest Park, and Powers Marine Park. Therefore, although isolated wildlife habitat areas along the lower Willamette River corridor exist, linkages to the larger landscape, such as Forest Park, are limited to a few areas. Forest Park, the largest of these upland habitat areas, is generally isolated from the lower Willamette River by the industrial corridor with the exception of a few small controlled watercourses. The barrier presented by the industrial corridor is unlikely to significantly inhibit the movement of birds between the river and the upland forest; however, it poses a significant barrier to the movement of other types of wildlife, such as reptiles, amphibians and small mammals, which, as a result, experience limited or no connectivity to the river.

Urban nesting sites, such as bridges and chimney roosts; bluff areas; grasslands at Powell Butte; native oak assemblages; bottomland hardwood forests; and wetlands have been identified in the vicinity of the study area (City of Portland 2008a).

Potential general wildlife habitat areas in the study area are shown on Map 3.1-19. These include the sites identified by the City of Portland (Adolfson et al. 2000) or based on field observations made during the shorebird habitat reconnaissance (Windward

2004, pers. comm.) or site bathymetry. In the City of Portland's inventory (Adolfson et al. 2000), 15 sites of habitat value for fish, reptiles, amphibians, and wildlife were identified. These habitat sites are known to be utilized by numerous aquatic birds and semi-aquatic mammals. Notable habitat sites in the study area include the South Rivergate corridor at the north end of the study area, the Harborton forest and wetlands, Willamette Cove, the railroad corridor, and the Swan Island beaches and lagoon on the southern end (Adolfson et al. 2000). Other habitat sites identified in the general area were Kelley Point, at the confluence of the Willamette and the Columbia rivers, and the Ross Island and Oaks Bottom Complex around RM 16.

The following provides some more notable habitat features throughout the site:

#### 3.1.7.2.1 Western Shoreline Habitat Features

- RM 0 (confluence with Columbia River) to RM 3 (Multnomah Channel), Sauvie Island—Riverbank is an earthen levee with variable width beaches, some natural vegetation, and occasional riprap.
- RM 3 to 3.2 (PGE Harborton)—Shoreline is a combination of riprap and rubble overgrown with vegetation, making it natural appearing. Habitat is available for shorebirds, amphibians, and aquatic plants.
- RM 3.2 to 4.1—The shoreline character is a mixture of natural-appearing and man-made conditions including riprap, rubble, and piling structures.
- RM 4.1 to 4.8—Natural-appearing riverbank and shoreline covered with cottonwoods and brush with narrow beach area.
- RM 4.8 to 11.2—Shoreline conditions range from riprap and rubble to pier and pilings, although there are some isolated natural-appearing areas.
- RM 11.2 to 12.2—The shoreline consists of riprap along the entire segment.

#### 3.1.7.2.2 Eastern Shore Habitat Features

- RM 0 to 0.9 (Columbia Slough), Kelly Point Park—Largely natural-appearing with large cottonwood trees, beach, and shoreline.
- RM 0.9 to 5.8—Shoreline condition varies, ranging from some vegetation and beach to bulkheads.
- RM 5.8 to 6.8, Cathedral Park—Natural-appearing riparian areas and beach.
- RM 6.8 to 7.8—A small area of natural-appearing shoreline vegetation adjacent to the railroad bridge. Articulated block on beach at McCormick and Baxter site with new plantings in riparian area. Remainder of shoreline is riprap or rubble. Small cove in front of Triangle Park property.
- RM 7.8 to 8.2—Natural-appearing with brush and cottonwoods. Steep riverbank with man-made alterations by the railroad.
- RM 8.2 to 9.2, Swan Island Lagoon—Shoreline character ranges from man-made piling structures to natural-appearing, though most is modified. Some

wildlife habitat area exists along east side of the lagoon. The extreme south end of the lagoon is currently undeveloped but has been filled to prohibit the Willamette River from flowing through the channel creating Swan Island Lagoon.

- RM 8.2 to 9.2—Entire shoreline is riprap.
- RM 9.2 to 10—Shoreline is riprap, but has sandy beach area.
- RM 10 to 12.2—Shoreline has been heavily modified with little natural vegetation, but some existing beach area. Between the Fremont Bridge and the Steel Bridge, the shoreline is heavily modified with riprap.

#### 3.1.7.3 Critical Habitat

Section 7(a)(2) of the ESA requires that any action authorized, funded, or carried out by the federal government is not likely to jeopardize the continued existence of listed species or result in the destruction or adverse modification of designated critical habitat for any listed species—in this case, salmon and steelhead. “Critical habitat” is defined as 1) specific areas within the geographical area occupied by the species at the time of listing, if they contain physical or biological features essential to conservation of the species, and those features which may require special management considerations or protection; and 2) specific areas outside the geographical area occupied by the species if the agency determines that the area itself is essential for conservation of the species.

The lower Willamette River has been designated by the National Marine Fisheries Service as critical habitat for Lower Columbia River Chinook salmon, Lower Columbia River steelhead, Upper Willamette River Chinook salmon, and Upper Willamette River steelhead (70 Fed. Reg. 52630), and is proposed critical habitat for Lower Columbia River Coho salmon (78 Fed. Reg. 2726). All of these species are anadromous, hatching in fresh water streams outside of the study area, migrating to salt water, and returning to fresh water to spawn. The study area provides migration and rearing habitat and both adult and juvenile salmonids are common in the lower Willamette River during various times of the year. Adults are present during their upriver spring migrations, whereas, juvenile salmonids can be found in the lower Willamette River year-round.

The critical habitat designations identified above (70 Fed. Reg. 52630, 78 Fed. Reg. 2726) indicate that freshwater rearing sites and migration corridors, such as provided by the study area, are essential to the conservation of the listed salmonid species. The critical habitat designations indicate that features of rearing sites that support listed salmonids include "water quantity and floodplain connectivity to form and maintain physical habitat conditions and support juvenile growth and mobility; water quality and forage supporting juvenile development; and natural cover such as shade, submerged and overhanging large wood, log jams and beaver dams, aquatic vegetation, large rocks and boulders, side channels, and undercut banks.” (70 Fed. Reg. 52630, 78 Fed. Reg. 2726). Features of freshwater migration corridors that support listed salmonids are that they are "free of obstruction and excessive predation with water quantity and quality conditions and natural cover such as submerged and overhanging large wood, aquatic vegetation, large rocks and boulders, side channels, and undercut banks supporting juvenile and adult mobility and survival." (70 Fed. Reg. 52630, 78 Fed. Reg. 2726). Many of the critical habitat features discussed above are substantially degraded in the study area, and since the study area is essential for rearing and migration of ESA-listed salmonids, it may require substantial habitat improvement to promote the conservation and recovery of these species.

## 3.2 HUMAN USE

### 3.2.1 Demography

#### 3.2.1.1 Multnomah County

The Portland Harbor study area is located in Multnomah County. As of the 2010 census (US Census Bureau 2010), there are 735,334 people residing the Multnomah County, most of whom reside within the City of Portland (see Section 3.2.1.2) and half (50.5 percent) are women. The population density is approximately 1,705 people per square mile with a per capita income of $29,544 (2011 dollars). Approximately 16.5 percent of the population is below poverty level.

There are 326,227 housing units with a median value of $281,900 and a 55.2 percent ownership rate. Each household comprises approximately 2.34 persons and a median household income of $50,726. The majority of the population (70 percent) is between the ages of 18 and 65, with 20 percent below the age of 18 and 10% above the age of 65.

The census reported the county as 81.2 percent White (597,091 people), 11.1 percent Hispanic or Latino (81,622), 6.7 percent Asian (49,267), 5.7 percent Black or African American (41,914), 1.5 percent Native American (11,030), and 0.6 percent Native Hawaiian or other Pacific Islander (4,412); 4.3 percent of the population reported belonging to two or more racial groups (31,619) and 14 percent were foreign born (102,946). Reportedly, 19.5 percent of the population (143,390) over the age of 5 speaks a language other than English at home.

The total number of firms[12] in Multnomah County in 2007 (2007 Economic Census) was 75,230. Of those, the census reports ownership as 86.8 percent White (65,300), 6.2 percent Asian (4,664), 3 percent Black (2,257), 3 percent Hispanic (2,257), 0.8 percent Native American (602), and 0.2 percent Native Hawaiian or other Pacific Islander (150). Women-owned firms comprised 31.6 percent (23,773) of the total firms.

[12] A firm may operate one place of business or more, such as a chain of restaurants, or have no fixed business location, such as the firm represented by a self-employed carpenter or salesperson. A firm contrasts with an establishment, which is a single physical location at which business is conducted. Most other data from the Economic Census are reported on an establishment basis rather than a firm basis.

The 2007 Economic Census data on the manufacturing sector[13] of Multnomah County reports manufacturers' shipments at $10.5 million, merchant wholesaler sales at $22 million, retail sales at $9.9 million, and accommodation and food service sales at $2 million.

#### 3.2.1.2 City of Portland

The city of Portland is located in Multnomah County at the upper bound of the Portland Harbor study area. Portland is the largest city in the state of Oregon and the 29th largest city in the U.S. As of the 2010 census, there are 583,776 people residing in the city of Portland (US Census Bureau 2010) and half (50.5 percent) are women. The population density is approximately 4,375.2 people per square mile. There are 265,439 housing units with a median value of $292,800 and a 54.2 percent ownership rate. Each household comprises approximately 2.27 persons.

The median income for a household in the city is $40,146, and the median income for a family is $50,271. The per capita income for the city is $22,643. The census reported 13.1 percent of the population and 8.5 percent of families are below the poverty line.

The census reported the city as 76.1 percent White (444,254 people), 9.4 percent Hispanic or Latino (54,875), 7.1 percent Asian (41,448), 6.3 percent Black or African American (36,778), 1.0 percent Native American (5,838), 0.5 percent Native Hawaiian or Pacific Islander (2,919), 4.7 percent belonging to two or more racial groups (24,437), and 5.0 percent from other races (28,987).

The age distribution was 21.1 percent under the age of 18 (123,177 people), 10.3 percent from 18 to 24 (60,129), 34.7 percent from 25 to 44 (202,570), 22.4 percent from 45 to 64 (130,766), and 11.6 percent who are 65 years of age or older (67,718). The median age is 35 years.

The total number of firms in the City of Portland in 2007 (2007 Economic Census) was 76,485. Of those, the census reports ownership as 86.2 percent White (65,930), 6.7 percent Asian (5,124), 3.1 percent Black (2,371), 3 percent Hispanic (2,294), 0.8 percent Native American (612), and 0.2 percent Native Hawaiian or other Pacific Islander (153). Women-owned firms comprised 31.9 percent (24,399) of the total firms.

The 2007 Economic Census data on the manufacturing sector of the City of Portland reports manufacturers' shipments at $8.4 million, merchant wholesaler sales at $20.6 million, retail sales at $8.2 million, and accommodation and food service sales at $1.8 million.

[13] Establishments engaged in the mechanical, physical, or chemical transformation of materials, substances, or components into new products.

### 3.2.2 Land Use

Land uses within the lower Willamette River watershed in the vicinity of Portland and its suburbs are urban/industrial, residential, and rural/agricultural. Many of the state's heaviest industrial users are present in the lower Willamette watershed. Land uses in the basin upstream of Portland include timber production, grazing, irrigated and dryland agriculture, and urban areas.

The east side of the lower Willamette River is relatively flat with little elevation change; consequently, the east side has been almost completely developed. The steeper slopes in the West Hills on the west side of the river developed more slowly. With a few exceptions, such as the Oaks Bottom complex, most of the natural riparian areas and wetlands on both sides of the river were filled over the past 150 years. The west side also has significantly more parks and open space, primarily because of Forest Park.

Portland Harbor and the lower Willamette River have served as a major industrial water corridor for more than a century. Industrial use of the study area and adjacent areas has been extensive. The majority of the study area is currently zoned for industrial land use and is designated as an "Industrial Sanctuary" on the Portland Comprehensive Plan Map (City of Portland 2006b). The Portland industrial sanctuary policy is designed to encourage the growth of industrial activities in the city by preserving industrial land. In addition to industrial use zoning designation, the City of Portland citywide zoning map (January 2009) displays several other zoning designations for smaller portions of the study area, including open space (e.g., Cathedral Park and Willamette Cove); general employment (mixed use allowed though primarily an industrial use focus); and multi-dwelling residential (e.g., University of Portland). The zoning codes apply to lands along the river and not to the actual river itself.

As shown in Map 3.2-1b-c, the Guild's Lake Industrial Sanctuary Plan (GLISP), which covers one portion of the study area zoned for industrial use, is intended to preserve and enhance industrial land in the Guild's Lake area, generally bounded by Vaughn Street on the south, the St. Johns Bridge on the north, Highway 30 on the west, and the Willamette River on the east (City of Portland 2001a). Over many decades, public and private investments in infrastructure, such as marine, rail, and highway facilities, as well as investments in industrial physical plants, have occurred within this area. The stated purpose of the GLISP is to maintain and protect this area for heavy and general industrial uses. The plan's objectives were adopted as part of Portland's Comprehensive Plan to ensure preservation of this land use over the next 20 years.

#### 3.2.2.1 Historical Development of the Lower Willamette River

This section summarizes the major historical land use, fill placement, and shoreline and overwater operations. Historical aerial photographs were reviewed to evaluate general trends in land use along the Willamette River waterfront. Mosaic images created by the Port of Portland from scanned historical aerial photographs of the river and waterfront were also reviewed, as were more recent aerial photographs (Maps 3.2-2a–f). The oldest historical aerial photographs available for this harbor-wide review were taken in

1936. Based on the pace of land development observed during the preliminary review of all of the aerial photo mosaics, six of the photo mosaics (1936, 1948, 1961, 1974, 2000, and 2007) were selected for broader-scale depiction of changes in land usage (Maps 3.2-3 through 3.2-8). For most years selected, aerial photo images were available for the entire river waterfront from the Columbia River to Ross Island.

Fill placement is shown on Maps 3.1-14a–f. Detailed information on the fill placement activities can be found in Table 3.2-1. Information used to construct this table was obtained from the aerial photographs, information collected by the LWG during the RI, and the City of Portland. The descriptions of subsurface soils in site investigation reports suggest that much of the fill placed in these areas consists of Willamette River sediment/sand/gravel dredged offshore of the respective facilities or in the immediate vicinity. Other sources of fill include dredged material from Multnomah Channel and the Columbia River. Anthropogenic sources of fill include concrete, brick, boiler ash, pencil pitch, Liberty ship bows, metal, asphalt, soil/slag material and construction debris. The source of the fill, if known, is identified in Table 3.2-1.

Overwater structures, such as wharfs, piers, floating docks, and pilings, were built largely to accommodate or support shipping traffic and remain common. These structures along the shoreline are clearly visible in the aerial photographs provided in Maps 3.2-9a–t.

Industrial and commercial development along the river began in the mid- to late-1800s in scattered areas such as downtown Portland, St. Johns, Linnton, and Macadam. Portland Harbor remained largely undeveloped through the late-1800s, but as urban development in the downtown area at the beginning of the 20th century pushed industrial development downriver, businesses began to relocate to the current industrial area of the harbor. The west side of the river was settled and developed first.

The most notable changes for the major reaches in the study area are described in the following subsections. These reach breaks are defined based on changes in the lower Willamette River's physical characteristics. General land use changes for the east and west banks of each reach are discussed, including historical riverbank fill placement and changes in overwater structures.

#### 3.2.2.1.1 RM 9.5 to 11.8

In 1936 the waterfront hosted a lumber mill, grain elevators, cargo docks, oil and coal exporters, and ship building and ship repair facilities. Rail yards between RM 10 and 12 were present on both sides of the river in 1936 and were more fully developed by 1948 (Map 3.2-2a). By 1961, industrial development had expanded on both sides of the river and log storage areas were present along riverbanks (Map 3.2-2b). Relatively few changes occurred from 1961 to 2000, with the exception of the completion of Interstate 5 and Interstate 405 (Maps 3.2-2c–e). By 2007, dock structures were added along the west bank and a few parcels were converted from commercial to industrial or residential use (Map 3.2-2f).

From approximately RM 9.5 to 10, the original shoreline on the east bank formed a cove. In the 1970s this area was filled (Map 3.1-14e). Significant channel narrowing due to infill on the west bank is observed from 1888 to 1936 (Map 3.1-14a). Beginning on the east side, the riverside area near RM 11.2 to 11.4 where Glacier NW is currently located (plus adjacent nonriparian properties) was the site of the former Albina Engine and Machine Works property, where ship construction and repair was conducted for the U.S. Navy and the War Shipping Administration (see Map 3.2-10). Albina Engine and Machine Works was founded in 1904 as a riverfront repair yard and operated until 1971. During WWII, the shipyard facility was expanded to encompass 16.8 acres and included six shipways, welding and pipe shops, paint storage and shops, warehouses, two outfitting docks, plate storage yards, burning slabs, and a pickling plant.

The shipways were filled beginning in the 1950s and completed by 1963. Most of the riverside buildings associated with the shipyard were demolished. The first new buildings on the former shipyard property appeared in the late 1970s. A portion of the former shipyard was used for expansion of the Pacific Power and Light Albina Substation beginning in the late 1940s.

Docks have been located in the area of the Albina Rail Yard (RM 10–11) and the Glacier facility (RM 11.3) from 1936 to the present day. From the review of aerial photographs, it appears the existing docks at the CLD Pacific Grain facility (RM 11.4) were constructed sometime between 1957 and 1966 (Map 3.1-14f). A large overwater structure called the Irving Dock was present at this location prior to construction of the present-day CLD Pacific Grain dock, as shown in both the aerial photographs and 1924 Sanborn maps reviewed by Integral. A large dock first appears in the 1961 aerial photo at RM 11.8E.

Along the west bank from RM 9.8 to 10.3, encompassing the present-day Terminal 2 and Sulzer Pumps properties, Willamette Iron and Steel Company (WISCO) operated a shipyard for an unknown period up until 1949 (Map 3.2-10). In 1941–1942, the WISCO facility was expanded with public funds from the Defense Plant Corporation. The reconfigured facility was 79 acres in total area, with government ownership of approximately 36 acres. Combined, these facilities provided a complete shipyard for launching and outfitting steel ships. Many of the manufacturing operations associated with the shipyard were located on the current Sulzer property (RM 10.3), which included outfitting operations, a sheet metal fabrication shed, a cable storage building, a machine shop, a paint shop, a coppersmith shop, and the main industrial building. WISCO operations consisted of three shipways with four attendant craneways located at the southern (upstream) end of the property; these shipways were subsequently filled in 1967–1968.

Significant changes occurred along the west bank with dredging of a slip at the WISCO shipyard in the mid-1940s (RM 10); the creation of the Albina Ferry slip (Slip No. 1) at Municipal Terminal 1 (RM 10) in 1914 and Slip No. 2 in 1923; filling of the western shoreline downstream of Terminal 2 (RM 10.6) in the 1950s and 1960s; filling of the

Terminal 1 South slip in the early 1900s; and filling of the Terminal 2 upstream slip by 1987 (Map 3.2-2e). Beginning with the 1936 aerial photograph, a large tank appears on the west bank at RM 12, but is no longer there in photographs taken after 1957.

Overwater features in this reach include the docks along the western shoreline at the former Municipal Terminal 1 and current Terminal 2 (RM 10 and 10.6), and an oil transfer pipeline (south of present-day Sulzer Pumps) at RM 10.4 (Map 3.1-14e). The oil transfer pipeline was used by PGE for transferring Bunker C oil from vessels to tanks at a nearby power plant. Some of these docks remain in place but are no longer in use. Most overwater activity associated with the docks in this reach appears to have occurred in the 1940s and 1950s, when the docks were used for loading lumber, paper products, grain, gravel, and coal. From the 1930s through the 1960s, log moorage rafts were present at approximately RM 9.2 and 10.

#### 3.2.2.1.2 RM 8 to 9.5

This stretch of the river has undergone significant change through the years, as is shown in the six photo mosaics (Map 3.2-2a–f). Swan Island (RM 8.3 to 9.2 on the east bank) was originally a sandbar and marsh separated by two channels of the Willamette River. Prior to 1920, the eastern channel was the river's main channel. The eastern channel was deeper than the western channel, which was wide and shallow with a shoal that hindered boat passage. In the early to mid 1920s, the west channel was deepened and widened in places to facilitate navigation (the west channel was opened to navigation in 1926). In 1927, the diversion of the river's main channel from the east side to the west side of the island was completed through the construction of a causeway at the island's upstream end (creating a lagoon out of the east-side channel called Swan Island Lagoon). The filling of Swan Island, performed by the Port of Portland, was mostly completed by the 1920s before construction began on the airport in 1926.

Mocks Bottom is located in the upland area east of the Swan Island Lagoon. Once a swampy slough, Mocks Bottom was filled by the Port of Portland and USACE to build roads and facilitate industrial development. About half of Mocks Bottom had been filled by 1961 and filling was complete by 1974 (Map 3.1-14d). Although some industrial facilities had developed along the shoreline by 1961, less than half of the area had been developed prior to 1974. The area was fully developed by 2007 with industry related to truck manufacturing, shipping and transportation, marine salvage, and military uses.

The Swan Island peninsula has a long history of commercial and industrial operations that continue today. The Swan Island Municipal Airport functioned until operations moved in 1940 to a location that is now part of the Portland International Airport. Between 1942 and 1949, the U.S. Maritime Commission leased Swan Island from the Port of Portland and contracted with the Kaiser Company to construct a shipyard and associated facilities. The shipyard facilities were used to build T-2 tankers used during WWII. A Kaiser affiliate, Consolidated Builders, Inc., conducted ship dismantling between 1947 and 1949. After the war, the area was redeveloped and used for ship repair purposes. The redeveloped facilities were used by various ship repair contractors and their subcontractors. In addition, facilities were leased to a number of industrial tenants who conducted a range of activities, including steel fabrication and storage, wood products manufacturing, equipment manufacturing, maritime supply sales, printing, chemical and soap storage, war surplus storage, fire extinguisher service and storage, paint storage, aluminum oil tank manufacturing, service station operation, sheet metal work, roofing supply storage, and general office storage. The eight shipways constructed during the military era were filled with dredged materials between 1950 and 1962. The current configuration of dry docks at the end of the peninsula and berths along Swan Island Lagoon and the Willamette River was largely completed by 1979. Some filling also occurred in the northwestern portion of the shipyard area in the late 1970s, and at the head of the lagoon by 1975 (see Map 3.2-2d).

Up until the 1960s the west side of the river was mostly undeveloped and was used for log raft storage. The present-day Shell Equilon dock occupied the west bank at RM 8.8 in 1936. Operations at Gunderson (RM 8.7 to 9.2) began as early as 1942, and most of the present-day site was constructed by 1966 (Map 3.1-14d); activities have generally included barge and railcar manufacturing. Ship building operations began at Gunderson in the 1960s and are still in operation today. During the 1960s and 1970s, a portion of the Gunderson facility was used by American Ship Dismantlers for ship scrapping. Overwater activities occurred at the barge launchways in Area 2 and the outfitting dock in Area 3. A dock structure and an oil transfer pipeline were located historically at the McCall Oil site (RM 8.2) prior to filling in the late 1960s. Fill was placed along the Gunderson shoreline beginning in the 1950s.

On the west side of the river in this reach, Guild’s Lake was a shallow, marshy area located from the present-day Guilds Lake Railroad Yard (otherwise known as “Lake Yard”) westward to St. Helens Road. Map 3.2-11 shows the location of the lake in 1888. Filling of Guild’s Lake began in approximately 1879 and was partially completed in 1913 by private entities using soil hydraulically sluiced from nearby hillsides, providing space for the rail yard and an industrial center (Oregon Historical Society 2002). The Port of Portland continued filling in the 1920s, using materials dredged from the Willamette River. The filling of the Guild’s Lake area was planned in connection with the West Swan Island project, where the channel was diverted from the east to the west side of the island. Construction of the Guilds Lake Yard, which is owned by Portland Terminal Railroad, began in 1916.

#### 3.2.2.1.3 RM 5 to 8

The 1936 photo mosaic (Map 3.2-2a) shows that the east side of the river was largely undeveloped from RM 5 to approximately 5.7 until the period between the 1960s and 1970s. Early features include docks at the McCormick and Baxter site (RM 7), Willamette Cove (RM 6.7) and downstream of Mar Com (RM 5.7). The eastern bank between RM 6.5 and 6.9 was primarily filled in the 1910s and 1920s to create the central and eastern parcels of the Willamette Cove upland facility. Upstream of RM 6.9, the eastern bank remained relatively unchanged until the 1970s, when the downstream end of the property presently known as Triangle Park (RM 7.4) was filled to create a dock and berth area. From 1888 to 1936, shoreline development is most notable from RM 5.9 to 6.4, due to the construction of the St. Johns Bridge at RM 5.9 and timber processing facilities on the eastern bank at RM 6.2 and on the western shore at RM 6 and 6.4. From 1888 to 1936 the eastern bank shows widening due to development in the vicinity of timber processing plants, including the McCormick and Baxter site (RM 7.1), and narrowing due to installation of the railroad crossing at RM 6.9 (Map 3.2-12a).

The Mar Com facility, which ceased operations in 2004, was situated on land that had been used for ship building and vessel repair since approximately 1905. The central parcel of the Willamette Cove facility was also used for ship repair on dry docks and related ship maintenance between 1903 and 1953. Upland shops and structures and in-water dry docks were used by independent contractors working for various vessel owners. During wartime, U.S. government contractors utilized the dry docks for military ship outfitting and repair. Several of these dry docks have since been removed from this stretch of the river (e.g., Mar Com, Willamette Cove). Dock structures at the former McCormick and Baxter facility were removed during the recent Superfund cleanup of this site.

The 1936 photograph of the west side of the river (Map 3.2-2a) shows the Willbridge Terminal (RM 7.5), U.S. Moorings (RM 6), and Gasco (RM 6.2) facilities with very little other development. Most of the shoreline change occurred on the west side of the river from the 1940s to the 1960s. Fill was placed along the eastern shoreline of RM 5 to 5.7 from the 1950s through the 1970s. By 1975, fill was also placed along the western shoreline and in a larger low-lying area at what is present-day Siltronic (RM 6) and Gasco property. Fill materials for both sides of the river included quarry discards and dredge materials. At the Gasco and Siltronic properties, manufactured gas production (MGP) materials were also included in the fill.

At the Arkema site (RM 7.2), which began operations in 1941, fill consisted of plant debris composed of asphalt, concrete, pipe, soil, and fill from other sources (e.g., City of Portland). Historically, fill materials were used to extend the ground surface out into the Willamette River. By the late 1980s, approximately 12 trenches on Lot 1 were filled with asbestos-containing residue. These trenches were believed to be approximately 60 ft long by 15 ft wide by 15 ft deep (DEQ 2001). The asbestos material was removed from the Arkema site in 1992 under a work plan approved by DEQ and under the agency's oversight (ERM 2003).

A DDT trench was located on Lot 1 and was investigated in the fall of 1992 (ERM 2003). The investigation determined that the trench was approximately 30 ft wide by 80 ft long and approximately 10–11 ft deep. The top of the trench was located 3 ft bgs. Because the trench was a clearly defined, discrete unit, the trench was completely excavated during the summer of 1994. Approximately 1,700 tons of soil were removed from the site and disposed of at the Waste Management Subtitle C landfill in Arlington, Oregon (ERM 2003).

On Lot 2, brine wastes were directed to a brine residue pile or pond until the early 1990s. The brine pile and pond were completely removed from the site in February 1989 and August 1992, respectively. The material was transported to the Hillsboro Landfill and beneficially used as a soil amendment to the final landfill cap (ERM 2003).The historical 80-acre Doane Lake and associated wetlands were situated in the upland area of this western stretch of the river (see Map 3.2-11).

The lake was divided in 1908 when the Railroad Bridge and southbound rail lines were constructed, and again in 1968 when the northbound rail line was constructed. The 6-acre lake area between these two rail lines is called North Doane Lake. The portion of the lake north of the Railroad Bridge was filled between the 1960s and 1970s for industrial development using 30,000 cubic yards of coal tar from a coal gasification plant.

The portion of the lake south of the Railroad Bridge was used for waste disposal by adjacent industries, including 80,000 tons of battery casings and lead-bearing materials and 6.5 million gallons of sulfuric acid (Gould Industries), pesticide and herbicide manufacturing wastes containing chlorinated phenolic and aromatic compounds (Rhone Poulenc), and foundry waste containing highly alkaline calcium hydroxide and mildly radioactive zirconium sands (ESCO). Between 1945 and 1955, stormwater and untreated wastewater from Rhone Poulenc was discharged to Doane Lake where it commingled with stormwater and releases from Gould/NL Industries, Schnitzer/Air Liquide, and ESCO. Doane Lake was almost completely filled by the late 1990s when the Gould Superfund site completed remediation.

The western shore shows narrowing from RM 6.9 to 7.4 due to upland development and installation of the railroad crossing. Arkema maintained two dock structures for receipt of evaporated sea salt, which contained sodium chloride, and shipping of inorganic chemicals produced onsite. Operations ceased in 2001, and the facility has been dismantled, but the dock structures remain. Petroleum products have been loaded and unloaded at the Willbridge Terminal since the early 1900s. A large dock offshore of the NW Natural facility at RM 6 is used by Koppers Inc. for unloading heated liquid coal tar pitch via cargo vessel. Fuel and Marine Marketing, Inc. also uses the dock to transfer petroleum products from barges to their bulk storage facility.

#### 3.2.2.1.4 RM 3 to 5

Major facilities on the east side of the river started in the early 1920s and included cargo handling, a flour mill, warehousing, and bulk fuel storage. Tank farms were developed on the west bank in approximately 1918 (present-day Kinder Morgan Linnton Terminal) and were expanded in the 1960s to be the predominant land use. The Owens-Corning Linnton facility installed several petroleum product tanks for use in their asphalt production in 1981. Other early west-shore industries included lumber mills, toy manufacturers, a creosote plant, and lumber storage. The PGE Harborton substation at RM 3.1W was constructed in 1985. Both sides of the river were fully industrial by the 1970s.

The most important shoreline changes in this reach occurred along the eastern shoreline from RM 4.2 to 4.6 (Map 3.1-14b). In the late 1910s and early 1920s, the mouth of Gatton Slough was filled (discussed in the following section), and three slips were dredged forming the Municipal Terminal No. 4 area (present-day Slips 1 and 3 and Wheeler Bay). Between approximately 1948 and 1958, the middle slip (Wheeler Bay) at Terminal 4 (which was never completed) was backfilled and Slip 3 was widened. The Port of Portland's auto storage facility at Terminal 4 was developed in the 1960s and the early 1970s, by placing sand fill to bring the site up to an elevation above the flood level. In the early 1970s, the sand fill was graded and the automobile storage yard and the steel dock and steel yard were constructed (Hart Crowser 2002c).

The Burgard Industrial Park (RM 4E) was the location of a large shipyard operated by the Oregon Shipbuilding Corporation. The deep-draft International Terminal Slip was created during the 1940s, and portions of the marshy, low-lying areas on the site were filled. Ship breaking activities were reported in 1946 (Oregonian 1946). The year in which shipyard was dismantled has not been presented in documents reviewed, but the shipways were filled between the early 1960s and 1972. Post-shipyard industrial uses included metal fabrication, log rafting, and upland log storage. The property was converted for use in 1972 as a metals scrap yard. Automobile shredding operations began in 1980.

Conspicuous historical overwater features within this reach include docks associated with ship building and repair, lumber mills, petroleum product distribution, moorage, and cargo unloading. Port of Portland Terminal 4 tenants that currently (or historically) handle soda ash, new automobiles, and liquid bulk materials from their docks are located on the eastern shoreline. Metal scrap delivery occurs at docks in the International Terminal Slip (RM 3.7). Along the western shoreline, there are bulk petroleum distribution docks (ARCO; RM 4.9) and sand and gravel unloading/loading overwater activities (Columbia River Sand & Gravel; RM 4.5).

#### 3.2.2.1.5 RM 1 to 3

Little change to the shoreline occurred in this vicinity of the river until fill materials were placed at the present-day Evraz Oregon Steel Mills (EOSM) site (RM 2.1E) from the early 1940s to the 1960s; additional filling of the riverbank occurred in the 1970s using EOSM slag materials, onsite soils, dredge material, and imported materials (Map 3.1-14a). Within the larger Rivergate industrial area, approximately 500 acres of the historic Ramsey Lake, located between Smith and Bybee lakes and the Willamette, were filled with dredge material from the 1960s to the 1980s. As shown on Map 3.2-11, this lake and floodplain historically covered approximately 650 acres and included a seasonal stream called Gatton's Slough that flowed west to the Willamette and a channel connecting it to the Columbia Slough to the east (USC&GS 1888). A dredge/fill map compiled from USACE data shows dredge material from the Post Office Bar and the mouth of the Willamette being placed in the Rivergate industrial area (Port of Portland 1981; USACE 1973).

The primary overwater features along the eastern shore of this reach are docks for distribution of chemicals and petroleum products. From 1936 until the 1960s, the eastern shoreline was utilized for log raft storage. In the 1940s, a dock was constructed at what is now the EOSM site for the transport of oil and bilge water to an upland oil sump. The current dock at Ash Grove is first present in the 1966 aerial photograph (Map 3.2-2c). By 1975, new docks associated with EOSM, JR Simplot, and Port of Portland Terminal 5 are present along the RM 1 to 3 reach.

The only industrial feature on the western bank of the river in this area is Alder Creek Lumber Company (RM 2.9).

#### 3.2.2.1.6 Multnomah Channel

Besides the Alder Creek lumber yard at the mouth of the Multnomah Channel, the only other predominantfacilities in this stretch of the channel are Fred's Marina, the Multnomah Yacht Club, and the ESCO landfill.

Since 1959, floating logs have been delivered to the dock area at the Alder Creek Lumber property near the mouth of the channel. Houseboat and boat moorages and marinas line Multnomah Channel's southern bank, opposite the ESCO landfill, forming a continuous string that extends as far as 1 mile. Approximately 200 of these houseboats and sailboats are used as permanent residences (DEQ 2009a).

Fred's Marina has occupied its site since the 1940s (Parson Brinckerhoff 2004). Presently, the marina contains a boat ramp, fuel dock, a boat trailer storage area, and over 200 slips. A designated dredged material disposal site is located upland directly east of the marina. This disposal site is for the containment of material dredged from the marina and vicinity that is deemed suitable for upland placement. The Multnomah Yacht Club has been in operation since 1961; prior uses of the property are unknown. The ESCO landfill does not have any operations on the shoreline. No further information on historical shoreline and fill placement activities was found.

### 3.2.2.2 Current Land Use

Portland Harbor is located within a broader region characterized by commercial, residential, recreational, and agricultural uses. A portion of the land adjacent to Portland Harbor is located within the GLISP (City of Portland 2001a) area (from the St. Johns Bridge at RM 5.8 to 10.7, along the west shore). Land use along the Willamette River within the harbor includes marine terminals, various manufacturing facilities, and commercial operations, as well as public facilities, parks, and open spaces. As shown on Maps 3.2-1a–e residential areas on the west side include the Linnton neighborhood in pockets west of St. Helens Road between RM 4.3 and 5W, and in the mixed use Pearl District neighborhood in the vicinity of RM 12W. Most of the residential land use on the east side is above the bluff, except for the St. Johns neighborhood, which extends closer to the river between RM 5.7 and 6.8E.

Maps 3.2-1a–d illustrate current land use zoning within the lower Willamette River and upper Multnomah Channel and show sites located within study area drainage basins. Waterfront properties are also labeled. Current and previous facility names for these sites are listed in Table 3.2-2.

The current overwater structures, such as wharfs, piers, floating docks, and pilings, were built largely to accommodate or support shipping traffic. These structures along the shoreline are clearly visible in the aerial photographs provided in Maps 3.2-9a–t. Numerous public and private outfalls, including stormwater and CSO outfalls, enter both shores of Portland Harbor, and are described further in Section 3.2.3.1.11.

The St. Johns Town Center is a mixed-use district that extends to the waterfront on the east side of the Willamette River at the St. Johns Bridge. The St. Johns/Lombard Plan (City of Portland 2004) includes a proposed redevelopment of this area near the Willamette River. The Riverfront Subdistrict included in the St. Johns/Lombard Plan is currently zoned as Open Space and as a Central Employment (EX) zone. The development standards of the Central Employment (EX) zone are intended to ensure that the Riverfront Subdistrict is developed in a manner consistent with adjacent areas and to support existing industry by limiting uses that may be less compatible with industry (City of Portland 2004).

Submerged lands are primarily owned by the Oregon DSL and leased to upland property owners for uses such as construction of overwater structures, moorage, etc. The DSL submerged lands boundary can be ordinary high water (OHW), ordinary low water mark (OLW), or arbitrary deed lines specific to each riverfront property. Notable exceptions to DSL ownership include portions of the submerged and submersible lands at the Port of Portland Terminal 4, most of the dry dock area and riverside berths at Swan Island, which are owned by Shipyard Commerce Center LLC, and the International Terminal Slip owned by Schnitzer Steel Industries. DSL owns approximately 94 percent of the submerged lands in the study area. There are also areas within the study area below OLW not owned by DSL or the Port of Portland (DEA 2011).

### 3.2.3 Site Use

This section describes the current understanding of the physical and biological setting of the study area as it pertains to potential human uses, including specialized groups that may use the river for various activities. Most of the demographic information relating to the study area is based on historical background and documented human uses. This information is used to determine potential receptor populations and to develop the general CSM.

### 3.2.3.1 Commercial and Industrial

This section provides an overview of Portland Harbor's waterfront land and harbor use. Over the past 100 years, major physical alterations have modified the river hydrodynamics and changed the configuration of the river. Map 3.2-11 shows the configuration of the river and the existence of nearby lakes in 1888 (USC&GS 1888). Shoreline changes are presented by decade on Maps 3.2-12a–e. The first map shows the 1888 shoreline and the remaining maps represent a series of nine historical snapshots of the shoreline starting in the year 1936 and ending in 2007. The land use along the lower Willamette River is currently highly urbanized and industrialized. Some remnant natural areas remain and support habitat for aquatic and terrestrial wildlife.

Significant physical modifications to the river coincided with the development and industrialization of the harbor. Modifications included redirection and channelization of the main river, draining of seasonal and permanent wetlands and lakes in the lower floodplain, extensive filling of wetlands along the shoreline, conversion of agricultural lands, and periodic dredging to maintain harbors and the navigation channel.

Commercial and industrial development in Portland Harbor accelerated in the 1920s and again during World War II, which reinvigorated industry following the Great Depression. Before the war years, industrial development primarily included sawmills, MGP, bulk fuel terminals, and smaller industrial facilities. During World War II, a considerable number of ships, minesweepers, and tankers were built at military shipyards located in Portland Harbor. Additional industrial operations located along the river during the shipyard years, including wood-treatment, agricultural chemical production, battery processing, ship loading and unloading, ship maintenance and repair (e.g., sandblasting, scaling, repair, painting, refueling), and railcar manufacturing. Many of these operations continue today. Coincident with the development and use of Portland Harbor for these industrial purposes were a number of fires that occurred at wood products industries, manufacturing plants, or other waterfront facilities that were constructed predominantly of wood (Oregonian 1958; 1966a,b; 1967).

The development of the harbor centered on several industrial sectors, which are described in the following sections. Each sector discussed below contains a map showing the historical and current facilities included in the industrial sector (Map 3.2-10 and Maps 3.2-13 through 3.2-21). The approximate location of facilities is shown on the maps, based on the current ownership of the property. Mapping of actual facilities or operations was not attempted. Only a few sites in each category are discussed.

#### 3.2.3.1.1 Ship Building, Dismantling, and Repair

Ship-related activities in Portland Harbor include ship building (1800s–present), ship repair (1800s–present), and ship dismantling (1960s–1979). In the early 1900s, ship building plants in the harbor constructed various types of wooden and steel vessels, including ocean-going and river boats. A 1919 Dock Commission map (CPD 1919) lists seven facilities producing wooden boats, four facilities producing steel boats, and two outfitting companies. The Grant Smith-Porter shipyard, at the present-day Mar Com North parcel, launched 25 wooden cargo ships in 1918 to support the Emergency Fleet Corporation (EFC) during World War I. This shipyard was the most prolific company in the EFC wooden ship program at this time. Prior to World War I, the steel ship building industry in the Pacific Northwest was not extensive due to the distance from steel-producing centers. Only one shipyard, just upstream from the Portland Harbor area, the Columbia River Shipbuilding Yard at RM 14W, produced steel ships for the EFC effort (Hopkins 1994). By 1935, the number of ship building facilities decreased to two: Albina Engine and Machine Works at RM 11E, and WISCO at RM 10W (CPD 1935).

Ship building accelerated again during the World War II years. Map 3.2-10 shows the general location of historical shipyards visible on aerial photographs taken between 1936 and 1969. Approximate areas of the former shipyards include RM 4E (Oregon Shipbuilding Corp.), RM 5.6E (U.S. Shipping Board), RM 6.7E (St. Johns Dry Docks, also called the Port of Portland Dry Docks on the CPD [1935, 1945] maps), RM 7.4E (Peninsula Ship Building Co.), RM 9E Swan Island (U.S. Maritime Commission), RM 9W (American Ship Dismantlers), RM 10W (WISCO), and RM 11E (Albina Engine and Machine Works).

As the demand for new ships increased, industrialist Henry Kaiser built two large shipyards, including the Oregon Shipbuilding Corp. shipyard at the present-day International Slip and the Swan Island shipyard. The Gunderson Brothers Engineering Group (RM 8.5–9.2W) also increased its plant's capacity to build small vessels. Besides Liberty ships, these facilities built small aircraft carriers, T-2 tankers, and a variety of landing craft that delivered troops, tanks, trucks, and supplies to combat zones. The population of Portland increased by a third as people moved into the city to work in the shipyards (Portland Tribune 2009; Oregon Historical Society 2002).

After the war ended, the salvaging of Liberty ships continued to fuel Portland's economy. Zidell Exploration Company salvaged many of the Liberty ship parts, except for the bows, which were reinforced with concrete when they were built. Many of these ship bows were buried along the west side of the Willamette just north of the Broadway Bridge. Ship dismantling and scrapping also took place at other facilities in Portland Harbor, such as Consolidated Builders, Inc., a Kaiser affiliate, which scrapped decommissioned troop landing ships at Swan Island for a short time, and American Ship Dismantlers located at the present-day Gunderson site (Portland Tribune 2009) and in the International Slip.

Ship repair also occurred at several facilities. Ship repair and related maintenance was conducted at the former St. Johns Dry Docks (aka Port of Portland Dry Docks) at Willamette Cove between 1903 and 1953, at Albina Engine and Marine Works between 1904 and 1971, and at Mar Com between 1905 and 2004. Other sites with historical ship repair activities include the Triangle Park and U.S. Moorings sites.

Ship-related activities continue at a much smaller scale in Portland Harbor today, with most work focused on ship maintenance and repair. At Vigor Industrial on Swan Island (formerly Cascade General), current activities at the dry docks include hull repair, maintenance, painting, and other dry lay-up ship repair tasks. The U.S. Moorings site (RM 6W) continued to do vessel repair until 2008. More than 2,000 marine vessels have been built at the Gunderson facility (RM 10.5W) since the 1960s, including ocean-going barges, conventional deck barges, double-hull tank barges, railcar/deck barges, dump barges, and barges for aggregates and other heavy industrial products.[14] Houseboats and sailboats are currently being built at RM 5.8W.

Chemicals such as VOCs, SVOCs, PAHs, PCBs, TPH, copper, zinc, chromium, lead, mercury, phthalates, and butyltins are identified as common contaminants associated with ship building, salvaging, and repair in studies by the National Shipbuilding Research Program (NASSCO 1999) and USEPA's Office of Compliance (USEPA 1997a), as well as USEPA's Industrial Stormwater Fact Sheet Series (USEPA 2006c). The antifouling paint applied to ships during World War I contained significant amounts of both zinc oxides and mercury oxides (Williams 1911). In modern times, antifouling paints are formulated with toxic copper, organotin compounds, or other biocides—special chemicals which impede growth of barnacles, algae, and marine organisms. In the 1960s and 1970s, commercial vessels commonly used bottom paints containing tributyltin ion (TBT), which has been banned by the International Maritime Organization (IMO 2002) due to its serious toxic effects on marine life.

#### 3.2.3.1.2 Wood Products and Wood Treating

The wood product industry has a long presence in Portland Harbor and has included wood-treating facilities (1944–1991), sawmills (1800s–1977), and plywood manufacturers (1905–2001), each with its own unique COIs. A 1919 Dock Commission map (CPD 1919) shows eight docks in the harbor devoted to lumber, the largest of which was Peninsula Lumber Company located at RM 7.4E on the McCormick and Baxter site and a portion of the Triangle Park site. Wood products created during this time included wooden barrels and box shooks (or box parts), which were shipped to fruit-growing areas or filled with local produce and railed to their destinations. The lumber industry grew exponentially during the war years, when barges pulling floating logs were a common sight in Portland Harbor. By 1977, the last sawmill in Portland was dismantled (MacColl 1979).

Lumber mills and wood treatment facilities operated at various locations within the study area historically, primarily RM 6.9 to 7.2E (Map 3.2-13). One of the largest sites was McCormick and Baxter, which produced treated wood for over 45 years. Other facilities that had wood-treating operations include West Oregon Lumber Co. (located at the Owens Corning-Linnton site) and Kingsley Lumber (at the Georgia Pacific-Linnton site). Wood-treating products used at these facilities include creosote/diesel oil mixtures, pentachlorophenol (PCP)/diesel oil mixtures and associated dioxin

[14] Gunderson Marine: http://www.gbrx.com/Marine_Barges_Home.php?expandable=2.

contaminants, and a variety of water- and ammonia-based solutions containing arsenic, chromium, copper, and zinc (Integral and GSI 2005a,b,c; USEPA 2004a, 2006d).

The present-day Georgia-Pacific Linnton facility (RM 3.6W) was formerly occupied by a sawmill, creosote plant, a lumber storage facility, and, before the site was mothballed in 1997, a wood chip transfer facility. The historical sawmill was owned by the Kingsley Lumber Company and ceased operations in the late 1960s. A sawmill also operated at the current Mar Com South property for almost 50 years. An additional sawmill operated in the central parcel of the Willamette Cove site from the 1950s until the early 1960s (Hart Crowser 2003). The Alder Creek Lumber Company in the Multnomah Channel has been the site of lumber-related activities (log storage, sawmill, lumber, planing) since its development in 1959 (Integral and GSI 2005a,b,c). While most of the byproducts of these operations were organic materials, contaminants typically associated with saw mills include wood preservatives (e.g., arsenic compounds, copper compounds, chromium compounds, pesticides, fungicides, biocides, borates, PCP, creosote, etc.), solvents, heavy metals, acid/alkaline wastes, benzene, TPH (oil, grease, diesel, gasoline), and PAHs (USEPA 2006d).

Various pesticides and fungicides have been used in glues and surface treatments in the plywood manufacturing process (Stellman 1998). The first plywood panels to be manufactured from western woods were made in St. Johns, Portland, at the Plywood Manufacturing Co. in 1905 (PPA 1967). The last plywood manufacturer in the harbor, Linnton Plywood, closed in 2001. The St. Johns Lumber Company (aka Portland Lumber Mill, Portland Manufacturing Co.) operated on the present-day Crawford Street and City of Portland Bureau of Environmental Services (BES) Water Pollution Control Laboratory sites from the 1930s until 1974 when the mill was demolished (Integral and GSI 2005a,b,c). A plywood manufacturing plant was also located on the west parcel of Willamette Cove upland facility (RM 6.3E) from 1901 until 1963 when it became a lumber mill. Building materials such as lumber, plywood, and laminated veneer lumber products were produced at Linnton Plywood and the western parcel of Willamette Cove. Linnton Plywood used phenol-formaldehyde resin, sodium hydroxide, and petroleum hydrocarbons, such as oil, diesel, and kerosene in its plywood manufacturing process (Integral and GSI 2005a,b,c). Contaminants associated with plywood manufacturing include VOCs, SVOCs, TPH, and metals (USEPA 2006d). Transformers associated with the operations can include the potential for PCB releases and the use of boilers can result in dioxin/furan releases from burning waste fuels. Additionally, solvents, heavy metals, acid/alkaline wastes, benzene, TPH (oil, grease, diesel, gasoline), and PAHs can be associated with ancillary operations, such as maintenance and repair, at the facility.

#### 3.2.3.1.3 Chemical Manufacturing and Distribution

Within the study area, some facilities manufactured chemicals and some stored, repackaged, and/or distributed chemicals. Chemical plants, including Arkema and Rhone Poulenc (RM 6.8–7.5W) that manufactured pesticides and herbicides, were in place as early as 1941 (Map 3.2-14). The Arkema facility was an organic and inorganic chemical manufacturing facility that produced sodium chlorate, potassium chlorate, hydrochloric acid, perchlorate and DDT at various times until operations ended in 2001. At the former Rhone Poulenc facility, fertilizers and organic and inorganic pesticide formulations, sodium arsenite liquids, organochlorine insecticides and chlorophenoxy herbicides, acid/esters, and bromoxynil products were produced during its 49-year history (1942–1991). Transloading facilities such as Port Terminal 4 and Slips 1 and 3 have been used for ship loading of fertilizer and soda ash that have been unloaded from rail transport.

The Great Western Chemical Company (aka Quadra Chemicals Western and Brenntag Pacific on the present-day McCall Oil site) at RM 7.9W produces water treatment chemicals, dry and liquid industrial cleaning agents and sanitizers, oxygen scavengers, and steam-line treatment chemicals (Integral and GSI 2005a,b,c). Other manufacturers in the study area included Premier Edible Oils (edible oil), West Coast Adhesives (phenolic resins), JR Simplot (urea and anhydrous ammonia), ACF (waste treatment and disposal), Ash Grove Cement (cement), Master Chemical (janitorial cleaners), Mammal Survey & Control Service (rodenticides), Mt. Hood Chemical Corp. (cleaning supplies), and McWhorter Inc. (varnish, paint, and resins). These sites are also identified on Map 3.2-14.

A number of facilities packaged, stored, and/or distributed chemicals. Van Waters & Rogers (aka Univar) handled a wide range of industrial chemicals, including organic solvents, acids and bases, ammonia, and other materials, until it ceased operations in 1988. Other chemical distributors included Great Western Chemical at RM 9.2W on the Chase Bag site (chemicals unknown), Wilbur Ellis (pesticides and herbicides), Ashland Chemical (primarily solvents), and McKesson (Mt. Hood Chemical Property—food additives, pharmaceuticals, and mineral acids).

Contaminants associated with chemical manufacturing operations can vary, depending on the operations, but could include pesticides, herbicides, VOCs, SVOCs, dioxins/furans, and metals (USEPA 2006e). Transformers associated with the operations can include the potential for PCB releases, and the use of boilers can result in dioxin/furan releases from burning waste fuels. Additionally, solvents, heavy metals, acid/alkaline wastes, benzene, TPH (oil, grease, diesel, gasoline), and PAHs can be associated with ancillary operations, such as maintenance and repair, at the facility.

#### 3.2.3.1.4 Metal Recycling, Production, and Fabrication

Recycling, production and fabrication, and plating of metals occurred at several locations within the study area.

Metal salvage and recycling facilities operated in the study area (Map 3.2-15) at RM 4E (Schnitzer Steel—auto and appliance dismantling), RM 5.8W (Marine Finance), RM 7.2W (Gould/NL Lead), RM 7.3W (Schnitzer-Doane Lake), RM 8.5W (Calbag Metals), RM 8.8W (Gunderson—auto dismantling), RM 9.5E (Portable Equipment Salvage), RM 9.7W (Schnitzer Steel Recycling Yard on NW Yeon), RM 9.8W

(Nudelman & Son), and RM 10.3W (Calbag-Nicolai). The metals recycling business includes cutting, torching, segregating, storing, and distributing metals, as well as recovering metals from wire. The Gunderson facility has manufactured and refurbished railcars since 1913. Railcars were also refurbished at the ACF Industries property (RM 3.7W) for almost 23 years (Integral and GSI 2005a,b,c).

Metal production and fabrication currently takes place in the Burgard Industrial Park, and several sites in the RM 8 to 10.3W reach, including Dura Industries, NW Copper Works, American Machine & Gear (RM 9.8W), and two non-ECSI sites, Portland Bolt & Manufacturing (RM 9.6W) and The Willard Storage Battery Company, which manufactured storage batteries at the Chase Bag site from approximately 1952 to 1958.

The Columbia American Plating site operated as a commercial plating (primarily zinc) facility between 1975 and its closure in 2003. Contaminants associated with metal recycling, production, and fabrication industries are dependent upon the activities conducted, but generally include PCBs, oil and grease, lubricants, paint pigments or additives, ionizing radioactive isotopes, transmission and brake fluids, fuel, battery acid, lead acid, antifreeze, benzene, chemical residue, heating oil, petroleum products, solvents, infectious/bacterial contamination, asbestos, cyanide, phthalates, and heavy metals (USEPA 2006f,g,h,i). Ancillary operations, such as repair and maintenance, can produce these contaminants from hydraulic fluids, oils, fuels, grease and other lubricants, chemical additives, PCBs, fuel additives, antifreeze (ethylene glycol), battery acid, products of incomplete combustion, heavy metals, chlorinated solvents, mineral spirits, industrial solvents, immersion cleaners, dry cleaner solvents, paint solvents, and spent antifreeze.

#### 3.2.3.1.5 Manufactured Gas Production

MGP operations took place between 1860 and 1955. Portland Gas & Coke constructed an oil MGP facility, known as Gasco at RM 6.5W (Map 3.2-16), which operated between 1913 and 1955. The plant initially produced town gas and pressed lampblack briquettes that were sold in the Portland area as fuel. In 1923, the gasification process was modified to optimize aromatic generation and light oil recovery for use as motor fuel. Tar recovery and refining were incorporated into the process in 1925 to provide tar for use as a road binder. During the 1930s, the plant expanded, and in 1941 a coking plant began production of electrode grade coke and high-grade natural gas (HAI 2003). The Pintsch Compressing Company Gas Works at RM 11.7W operated between 1890 and the mid-1930s and manufactured compressed gas from crude oil for railroad train lighting. Just upstream from the study area, the Portland MGP site operated at RM 12.2W between 1860 and 1913. As the wastes produced by former manufactured gas plants are persistent in nature, they often (as of 2009) still contaminate the site of former manufactured gas plants: the waste causing the most concern today is primarily MGP tar (mixed long-chain aromatic and aliphatic hydrocarbons, a byproduct of feedstock carbonization), and purifier waste (composed of "purifier beds" made up of either lime or wood chips impregnated with iron filings and contaminated with sulfur and cyanide compounds from passing the gas through it). Contaminants associated with manufactured gas operations include VOCs (benzene, toluene, ethylbenzene, and xylenes [BTEX]), SVOCs, PAHs, TPH, metals, and cyanide.[15]

#### 3.2.3.1.6 Electrical Production and Distribution

Electrical transformers and capacitors are associated with nearly all of the major industries in the harbor. Transformers and capacitors historically contained and may continue to contain PCBs. There are seven current substations and one historical substation in the study area (Map 3.2-17). The PGE Harborton Substation at RM 3.3W currently consists of an operating 115-KV switchyard and distribution substation for electrical power regulation and transmission (Integral and GSI 2005a,b,c). PGE also operates Substation E (RM 10.4W), and other substations at Swan Island (RM 9.3E), Siltronic (RM 6.4W), and Willbridge Terminal (RM 7.5W). The PacifiCorp Knott Street substation is located at RM 11E, which is associated with a high-voltage cable crossing at RM 11.3. The remaining active substation is operated by Schnitzer Steel (RM 4E, near the International Slip). Bonneville Power Administration operated a substation at the Arkema site and conducted site cleanup after decommissioning the substation.

Electrical equipment repair, servicing, and salvaging operations occurred on the east bank from RM 11.3 to 11.5, including the Tucker Building (former electrical distribution and limited small transformer repair), Westinghouse (former transformer repair and servicing), and PacifiCorp Albina Substation Properties (Block 71, 81, and 82; electrical distribution only); at RM 3.7W (ACF Industries); RM 9.5E (Portable Equipment Salvage); RM 9.5W (GE Decommissioning); and RM 10W (GE facility at NW 28$^{th}$ Ave). The GE Decommissioning facility handled dielectric fluids containing PCB concentrations greater than 50 ppm up until 1978 after the enactment of the Toxic Substances Control Act (TSCA; AMEC 2004b). These fluids were drained from customer-owned equipment into temporary aboveground holding tanks or drums. Often these fluids were returned to the equipment following service or repair (AMEC 2004b). The GE facility at RM 10W conducted repairs from the mid-1990s to 2001, including decommissioning of custom transformers. From 1943 to 1978, the Westinghouse facility at RM 11.3E conducted electrical transformer repair services and purportedly handled dielectric fluids containing PCBs. Contaminants associated with electrical production and distribution include PCBs, TPH, and PAHs (Pfafflin and Ziegler 2006).

#### 3.2.3.1.7 Bulk Fuel Distribution and Storage and Asphalt Manufacturing

Bulk fuel facilities have a long history in Portland Harbor. By 1936, most of the facilities currently in place between RM 4 and 8 on the west side of the river had already been established (Map 3.2-18). These facilities include ARCO's BP Terminal, Kinder-Morgan, Willbridge Terminal, Christenson Oil, ExxonMobil, Texaco Equilon, and Foss/Brix Maritime. Five additional facilities were located on the east side of the river in the RM 3 to 5 reach: Time Oil owned and operated at two facilities, and three

[15] Heritage Research Center: http://www.heritageresearch.com/documents/More%20About%20Manufactured%20Gas.pdf

facilities were located at the Port of Portland Terminal 4 (Standard Oil, Quaker State Oil, and General Petroleum Corp.).

These facilities have handled a variety of petroleum products, including lubricating and specialty oils, bunker fuel, diesel fuel, gasoline, ethanol, gasoline additives (e.g., methyl *tert*-butyl ether [MTBE], ethylene dibromide [EDB], ethylene dichloride [EDC], lead), aviation fuel, and various lubricants. Petroleum product pipelines are also found throughout the study area.

Another petroleum product, asphalt, is manufactured at several facilities on the west side of the river, including Owens Corning Linnton (RM 3.8W), GS Roofing (RM 7.5W), McCall Oil (RM 7.9W), Chevron Asphalt Refinery (RM 8W), and Trumbull Asphalt (RM 9.1W). The Municipal Paving Plant at RM 10.9E was constructed in 1928 and operated intermittently until its permanent closure in 1966.

Contaminants typically associated with bulk fuel storage operations and asphalt operations include VOCs (benzene), SVOCs, PAHs, TPH (oil, gas and diesel fuels), and metals (USEPA 2006j). Additionally, gas/diesel fuel, fuel additives, oil/lubricants, heavy metals, brake fluids, transmission fluids, chlorinated solvents, and arsenic can be associated with ancillary operations, such as maintenance and repair, at these facilities.

#### 3.2.3.1.8 Steel Mills, Smelters, and Foundries

Since the early 1900s, metal foundries have been located in Portland Harbor (Map 3.2-19). For the first 30 years, these foundries served as suppliers of cast steel alloy products for the logging, construction, and pulp and paper industry throughout the Pacific Northwest. Today, these foundries manufacture products for a multitude of industries, including mining, highway and heavy construction, utilities and general construction, power generation, aerospace, defense, dredging, forestry, rigging, conveying, as well as many other industrial applications. Steel foundries are located at RM 2.8E (Consolidated Metco), RM 9.7W (Schmitt Forge), RM 10.4W (ESCO Main Plant), RM 10.5W (ESCO Plant 3), and RM 11.4W (Gender Machine Works). Lead smelters were located at RM 7.2W (Gould), at RM 9W (National Lead/Magnus Smelter), and at RM 11.6W (RiverTec Property). In addition to lead smelting, facility operations at the Gould site included lead-acid battery recycling, zinc alloying and casting, cable sweating, and lead oxide production. The present-day Wilhelm Trucking site at RM 9.6W was the former location of a lead bearing rehabilitation plant. Steel mills were located at RM 2.4E (EOSM) and at RM 8.3W (former Oregon Steel Mill operation at Front Ave LP). Only the EOSM property is currently operating, confined to steel production, steel processing, and related ancillary operations.

Besides metals, other contaminants associated with these types of operations include TPH (from oil, gas, and diesel fuels) and PAHs. PCBs were a component of hydraulic fluid for high temperature applications (machining, die casting) where fire resistance was important. PCBs were also a component of heat transfer fluid used in big applications like heat exchangers and recirculating cooling systems (USEPA 2004b).

Additionally, gas/diesel fuel, fuel additives, oil/lubricants, heavy metals, brake fluids, transmission fluids, and chlorinated solvents can be associated with ancillary operations, such as maintenance and repair, at these facilities (USEPA 2006g).

#### 3.2.3.1.9 Commodities Maritime Shipping and Associated Marine Operations

At the turn of the 19th century, Portland Harbor accommodated steamboats that transported farm products and natural resources from Idaho, eastern Washington, and Oregon. This cargo was then loaded onto sailing ships for markets in Asia, the eastern and western United States, and Europe. Portland Harbor also served as the gateway for incoming trade goods to the region. On the 1919 Dock Commission map (CPD 1919) there were docks dedicated to the distribution of shingles, cans, asphalt, sand and gravel, cereal, flour, grain, and vegetable oil.

The Port of Portland facilities have had a prominent presence in the maritime commodities shipping industry in Portland Harbor since 1891. Over the years, export/import of agricultural products, dry/liquid bulk products, forest products, and other bulk commodities have passed through Port facilities (Terminals 1, 2, 4, and 5). Currently, the Port operates two deep-water marine terminals, Terminals 4 and 5, within the study area that handle thousands of tons of cargo each week. Major exports handled at Terminals 2 and 4 (Map 3.2-20) include pencil pitch, wheat, soda ash, potash, and compressed hay. The Port's operations in Portland Harbor constitute the third-largest export center for grain in the world and the largest wheat export port in the United States (Williams 2007). Major imports include automobiles, steel, and limestone.

Other privately owned commodity shipping facilities in the harbor include or have included the grain handling operations at CLD Pacific Grain (RM 11.4E) and Centennial Mills (RM 11.3W), edible oils at the former Premier Edible Oils facility (RM 3.6E), scrap metal export at International Terminals (RM 4E), cement import and distribution at Glacier NW (RM 11.3E), as well as other non-ECSI sites. JR Simplot in the South Rivergate Industrial Park (RM 3E) has been distributing anhydrous ammonia and solid and granular urea to the Pacific Northwest since 1968. Goldendale Aluminum at RM 10E was used as an offloading facility (alumina, electrode binder pitch, and grain) from 1957 until 2001 (Integral and GSI 2005a,b,c). Sand and gravel operations have occurred at the Ross Island Sand & Gravel facility at RM 11.1E since at least 1920 (Landau 2002b).

Contaminants for the commodities maritime shipping industry include spillage of raw materials during transport to and from vessels; butyltins, copper and zinc from ship hull paints; and oil, lubricants and grease from overwater transport equipment (USEPA 2006k). Supporting maritime activities include overwater tug and barge moorage, maintenance and repair facilities, overwater bunkering and lightering, tug-assisted and independent maneuvering of vessels in and around marine facilities, and stevedoring (loading and discharging) product at vessels. Contaminants such as gas/diesel fuel, fuel additives, oil/lubricants, heavy metals, brake fluids, transmission fluids, and chlorinated solvents can be associated with these support activities (USEPA 2006k).

#### 3.2.3.1.10 Rail Yards

In addition to the construction of commodity shipping facilities, railroads were constructed in the early 1900s to support the overland transport of farm products and natural resources from Idaho, eastern Washington, and Oregon. Rail tracks, yards, and terminals are located in the Portland Harbor area. Rail yards are found on the eastern side of the river at approximately RM 9.8 to 11.1 (Union Pacific Railroad [UPRR] Albina Yard) and RM 4.6 (UPRR – St. Johns Tank Farm), and on the western side of the river from RM 8.6 to 9.5 (Portland Terminal Railroad Guilds Lake Yard) and RM 8.1 (Burlington Northern Santa Fe Railway Co. [BNSF] Willbridge Switching Yard) (Map 3.2-21). These rail yards support the interstate railroads, BNSF, and UPRR.

Primarily operating as switching yards, some rail yards offer locomotive fueling and servicing, railcar maintenance, and trailer-on flatcar storage. Railcar switching yards (RM 8.1W—BNSF Willbridge Switching Yard) are locations where trains are assembled and disassembled (and this type of operation typically does not result in releases or produce waste streams). Historical rail yard operations were also located on the western side of the river at RM 11.6 (BNSF Hoyt Street Railyard, and UPRR Union Station operations). BNSF owned and operated the Hoyt Street Railyard from the early 1900s until 1988. The rail yard has been abandoned and dismantled, and much of the site has been developed as condominiums and commercial businesses. Historical railcar maintenance operations were also located at RM 3.7W (ACF Industries).

Contaminants associated with rail transportation facilities are dependent upon the activities conducted, but could include PCBs, oil and grease, lubricants, paint pigments or additives, transmission and brake fluids, fuel, battery acid, lead, antifreeze, chemical residue, petroleum products, solvents, asbestos, phthalates, and heavy metals (USEPA 2006l). Ancillary operations, such as repair and maintenance, can produce these contaminants from hydraulic fluids, oils, fuels, grease and other lubricants, chemical additives, PCBs, fuel additives, antifreeze (ethylene glycol), battery acid, and products of incomplete combustion, heavy metals, chlorinated solvents, mineral spirits, industrial solvents, immersion cleaners, paint solvents, and spent antifreeze. Contaminants associated with fueling activities and freight car repair operations at rail yards could include VOCs, SVOCs, TPH, PCBs, and metals (USEPA 2006l; DEQ 2011a).

#### 3.2.3.1.11 Conveyance Systems

This section describes the historical and current conveyance systems in the study area, including both municipal and non-municipal systems. Non-municipal systems are either private or part of other public systems, such as ODOT or the Port of Portland.

##### *General Description of Conveyance Systems*

There are three types of conveyance pipes in Portland Harbor. The following is a description of the types of flows each pipe carries and its discharge points:

- **Sanitary Pipes:** These pipes convey sanitary wastes from domestic and industrial sources, and may also carry industrial wastewater. Flows in these pipes discharge to the Columbia Boulevard Wastewater Treatment Plant (CBWTP), which discharges to the Columbia River at two discharge points (RM 105.5 and 105.6), approximately 4 miles upstream of the Willamette River confluence. Sanitary pipes are typically part of the City of Portland's collection system, although there are sanitary pipes on private property that connect to the municipal system.
- **Stormwater Pipes and Other Point Discharges:** Stormwater conveyance systems typically consist of ditches, swales, storm drains, inlets and catch basins connected to an outfall through pipes or lines. Flows in these pipes typically discharge to the river, although some may discharge to lakes or infiltration facilities. Stormwater pipes can be part of the municipal collection system or part of a non-municipal system.
- **Combined Pipes:** Combined pipes convey sanitary wastes from domestic and industrial sources and stormwater, and may also carry industrial wastewater. Historically, these flows typically discharged to the river. After combined pipes were connected to the sanitary interceptors, the outfalls draining these pipes were either converted to CSO outfalls or to storm-only outfalls. Historically, combined pipes were both municipal and non-municipal, but currently most combined systems are part of the City's collection system. Additional detail on how combined pipes function and the types of CSO outfalls is provided below.

**Outfalls**

Within the study area, outfalls have been installed by a variety of entities, including private landowners, the Port of Portland, the State of Oregon, and the City of Portland. Most of the outfalls currently convey primarily stormwater, although historically some also conveyed industrial and sanitary discharges.

Some outfalls also currently convey nonstormwater discharges. Some nonstormwater discharges, such as noncontact cooling water, must be permitted, while other nonstormwater discharges, such as landscape irrigation, are exempt under federal regulation. As discussed below, some outfalls include a CSO component as well.

The City of Portland identified over 400 potential public and private outfalls along both shores of the study area (City of Portland 2006c). Using site-specific information and field reconnaissance, the LWG independently verified these outfalls and researched areas that potentially had additional outfalls. Incorporating results of the field reconnaissance, a total of 436 outfalls were identified; of these approximately 313 are active, 44 are inactive, 30 are abandoned, 15 have been removed, 27 are unknown outfalls, and 7 were determined to not be outfalls (Integral 2008h).

The types of outfalls are defined as follows:

- **Active** = outfall is currently in use
- **Inactive** = outfall pipe exists, and is not filled, plugged, or disconnected, but discharge is presently not occurring
- **Abandoned** = outfall pipe exists but it is filled, plugged, or disconnected, and discharge is not occurring
- **Removed** = outfall pipe has been removed
- **Unknown** = despite best efforts, the status of some outfalls cannot be determined.

Attributes for some outfalls in the data set remain flagged despite repeated attempts by the LWG to verify during fieldwork or due to conflicting information from the facility and the City. The location and status of the outfalls within the study area are shown on Maps 3.2-22a–m.

**Stormwater Runoff**

Stormwater enters the river via stormwater conveyances, overland flow, and infiltration to groundwater. Stormwater conveyance systems typically consist of ditches, swales, storm drains, inlets, and catch basins connected to the outfall through pipes or lines.

Overland flow of stormwater occurs at some locations immediately adjacent to the river. In many of these areas, the extent to which rainwater falling on pervious ground near the river shoreline results in runoff versus infiltration into the ground is unknown. In some impervious shoreline areas, stormwater appears to be transported to the river via overland flow, with little chance for infiltration into the ground. A preliminary assessment of outfall drainage basins conducted for the Round 2 Report indicated that the area drained by overland flow appears to be relatively small compared to the area in which stormwater is discharged via outfalls. Given the difficulties of defining all stormwater conveyance drainage basins along the river, the proportion of overland flow to the river has not been further quantified for this RI. Nevertheless, this pathway may represent a significant contaminant transport pathway route, especially as it relates to riverbank erosion.

Additionally, stormwater can enter the river indirectly via infiltration into pervious ground (or through dry wells, sumps, and other infiltration facilities), where it is then mixed with groundwater and discharged to the river as groundwater. Groundwater discharges are further discussed in Section 3.1.3 and Section 4.

Most of the stormwater from the west side of the river drains from Forest Park, an area which consists mostly of undeveloped parkland. Streams from Forest Park generally enter underground pipes at the base of the West Hills, near U.S. Highway 30. At this point, the highway stormwater drainage often enters these same conveyance systems. This runoff is comingled with industrial stormwater runoff as it moves through industrial properties between the park and the river. On the east side of the river, there are few open channel drainages, and most of the stormwater is discharged via conveyance systems. Most properties adjacent to the river on both sides do not discharge through shared conveyance systems but directly discharge to the river via their own stormwater conveyance systems and outfalls or overland flow.

Just under half of the stormwater drainage to the study area is through shared conveyance systems; open space comprises about 60 percent of these basins. These systems are further discussed in Section 4.4.1.3 and include shared conveyance systems owned by the City, by Burgard Industrial Park, and by ODOT; multiparty outfalls with unknown ownership; and Saltzman Creek. In some locations, stormwater is captured by the City of Portland combined conveyance systems and is routed to CBWTP.

Section 4.4.1.2 further discusses the stormwater basins and the types of stormwater discharges, including a map showing a categorization of the different drainage types within the study area (i.e., shared conveyances, direct discharge, no discharge, and uncertain drainage).

Figure 3.2-1 shows the hydroboundary, the approximate overall area draining stormwater to the study area. The delineation of the overall drainage basin area between RM 1 and 11.8 was provided by the City of Portland (2006d). An analysis of stormwater flow contributions to overall river flows estimated that the Portland Harbor area runoff volume contributions are between 0.06 percent for the wet year conditions (1997) and 0.08 percent for dry year conditions (2001) of the total Willamette River flow. The average annual runoff volume for the Portland Harbor is 0.06 percent of the total Willamette River flow (City of Portland 2006d).

***Municipal Conveyance Systems***

This section summarizes information regarding the City of Portland's municipal conveyance system development in the study area. There are four major time periods discussed below. The initial period (1880–1947) was when most of the conveyances were combined systems. From 1948 to 1955, interceptors were installed and connected to most of the City's combined system (converting these outfalls to CSOs) and some separated systems were constructed. During the period from 1956 to 1990, sanitary service was extended to the northwest area and more separated systems were created. The final period describes the current conveyance systems and system development changes after 1990.

These pipe types are currently configured into three general types of conveyance systems in the study area, as shown in Figure 3.2-2: 1) separated systems, 2) combined systems that discharge to the CBWTP (with no discharge to the river), and 3) combined systems with overflow diverters designed to reduce discharge to the river to a maximum of four times per winter and once every three summers (City of Portland 2001b). Separated systems have stormwater-only lines that discharge to the river and sanitary-only lines that discharge to the treatment plant. In combined systems, the stormwater and sanitary lines join and flow in a combined line. Most of the study area is currently served by separate storm lines and separate sanitary sewers. Only a limited portion of the area is served by the combined system, and not all of the combined system has the ability to overflow to the river. Stormwater and combined systems are further described below.

Historically, municipal and non-municipal combined and storm pipes discharged directly to the river. When sanitary interceptors were constructed, parallel to the riverbanks, they intersected the municipal combined trunk lines. The combined trunk lines were connected to the interceptor system. Diversion structures in the combined pipes, essentially dams, direct flows that exceed the interceptor capacity to overflow to the river as illustrated in Figure 3.2-3.

The overflow system was built to prevent the interceptor system from being overwhelmed during a storm event. This overflow system allows flows to breach the diversion dams and discharge the combined storm and sanitary sewage flows through an outfall to the Willamette River. Any sewer connections at points in the trunk lines above the diversion structures would overflow to the river only when rainfall caused an exceedance of the approximately three-times-dry-weather flow capacity of the system (City of Portland 1969). Discharges to connections at points in the trunk line downstream of a diversion or connections directly to the interceptor could not overflow to the river during a CSO event. On average, a typical CSO contains about 80 percent stormwater and 20 percent wastewater. Once the interceptors were put in place, the outfalls were referred to as CSO outfalls (CH2M Hill 1992; City of Portland 1952a, 2001b; Stevens & Thompson 1964).

Diversions from the combined system to the river (i.e., CSO events) occur before flows reach the interceptor. Once flows have entered the interceptor, these flows are directed to the treatment plant. During construction of the interceptor system, pump stations were added, some of which included emergency overflow lines that were connected to outfalls, which are known as sanitary sewer overflow (SSO) outfalls. Thus, after the interceptor connections were made, any sewer connections made directly to the interceptor pipe could not overflow to the river unless there was an emergency failure at a pump station. Figure 3.2-4 shows the location of the interceptors and the SSO outfalls.

**1880–1947**

The first municipal sewers in Portland Harbor were constructed by the cities of Portland, Linnton, and St. Johns, starting in the 1880s. These sewers were located in the downtown areas of each of these cities. The Linnton and St. Johns outfalls were transferred to the City of Portland when these cities were annexed into Portland, in 1905 and 1915, respectively. These combined sewers collected both surface drainage and sanitary wastes (including domestic and industrial discharges) and, as all private and public sewers did during this time period, discharged directly to the Willamette River (City of Portland 1966a).

In 1936, 48 municipal outfalls directly discharged to the Willamette River (City of Portland 1936), located between RM 4 and 17. Nineteen outfalls discharged within the study area; these were located in the downtown core (between RM 9.6 and 11.8 on both sides of the river), in the St. Johns area (between RM 5.2 and 5.9 on the east shore), and in the Linnton area (between RM 4.3 and 5.3 on the west shore).

During and immediately after WWII, the City operated six additional combined conveyance systems. Two of these were constructed by the City to serve residential-only areas in St. Johns (OF-48 and OF-49). Two were constructed by the Federal Housing Authority, built to serve temporary housing for wartime workers (OF-18 and OF-19). Two were constructed by private parties to drain their site and then were transferred to the City under Public Works permits (OF-20 and OF-21). OF-20 was abandoned in 1949 and flows were redirected to OF-19. Table 3.2-3 identifies the locations of outfalls, including those constructed during this time period.

Initial scoping of the Sewage Disposal Project included several interceptor sewers and a treatment plant discharging to the Columbia River (Smith 1936). Construction of this project began in 1947 (City of Portland 1952a).

**1948–1955**

During this time period, the CBWTP and the northeast and downtown interceptors were constructed, and combined flows from the municipal trunk lines were connected to the interceptors. As shown in Table 3.2-3, within most of the City CSO basins in the study area, industrial areas were separated so that industrial wastewater would not overflow to the river during CSO events. The exception to this was the industrial area in the north part of downtown on the west shore, where separation was more difficult because the area had already been heavily developed. Primary treatment (solids removal) was also added to the two Linnton outfalls as part of the effort to reduce loading to the river. Also during this time period, the City constructed new outfalls or accepted existing outfalls.

In 1947 the City Sewage Disposal Project began the construction of two interceptor lines (the east side and the west side) and a treatment plant (OSSA 1964). Construction of the interceptor lines diverted most flows to the newly constructed CBWTP.

The interceptor system in Portland Harbor, as of 1952, is presented on Figure 3.2-5 (City of Portland 1952a); additional work that continued through 1954 is not shown in this figure. The first unit of the interceptor sewer system (serving northeast Portland) was completed in 1947. The CBWTP and the interceptor system on the east side of the Willamette River were completed in 1952. The eastside interceptor system extended from the southern limits of the city north to the treatment plant but did not include the Rivergate area, which was outside the city limits at that time (City of Portland 1952b). Of the eastside CSO outfalls, OF-43 through OF-53 discharged to the Portland Harbor study area.[16] During construction of the interceptor system, the City separated the sewers serving most of the industrial areas near the riverfront by building separated sanitary and industrial wastewater sub-basins connected directly to the interceptor, and separated stormwater systems that discharged directly to the river.

Some of these outfalls still had a combined system upgradient of the nearshore industrial separated area that served primarily residential areas. After the interceptors were installed, some properties that formerly discharged through private outfalls directly to the river had the opportunity to connect to the City's sanitary system (either to the new sanitary system installed or directly to the interceptor).

Also during this time, the City constructed a local treatment facility to provide primary treatment (solids removal) for the two Linnton outfalls (OF-23 and OF-24) that served primarily residential areas (City of Portland 1999).

By September 1955, the City had completed construction of the westside (including downtown) interceptors incorporating outfalls designated OF-1 through OF-17 (OSSA 1953, 1954a,b, 1955). Of these west side outfalls, OF-11 through OF-17[17] discharge to the Portland Harbor study area. Portions of the industrial area that had been connected to the combined system were connected to a separate sanitary sewer that discharged directly to the interceptor.[18] The areas with no separate storm and sanitary systems available continued to discharge to the combined system or discharged directly to the river. The interceptors and associated facilities reduced the volume of untreated sewage discharging to the Willamette from the City's combined system.

**1956–1976**

Once the eastside and downtown interceptors were installed, the only areas not served by City sanitary sewer system in Portland Harbor were the northwest (from Guild's Lake to Linnton), Swan Island, Mocks Bottom, and Rivergate areas (see Figures 3.2-5 and 3.2-6). The latter two areas were mostly undeveloped except for a few shoreline facilities. Conveyance systems in the northwest area were operated by private and City systems, and conveyance systems in the Swan Island area were operated by the Port of Portland.

During the time period of 1956 to1976, the City implemented a number of system changes to further reduce combined sewer discharges to the river, including programs to assure that properties connected to the City system were discharging to the appropriate pipe. The City constructed several separate sanitary and storm systems in areas that were undeveloped or were served by non-municipal combined systems. Also during this period, the City completed the northwest interceptor system, which separated stormwater and sanitary sewers in the northwest industrial areas and converted the

[16] OF-43 is at RM 11.4 and OF-53 is at RM 5.2.
[17] OF-11 is at RM 11.4 and OF-17 is at RM 9.6.
[18] Based on City as-built drawings for the interceptor and other separation projects. As-built drawings are available on the City's website: http://PortlandMaps.com.

Linnton neighborhood service areas to CSO areas. By 1975, the City's service area included both separated systems and CSO systems, including new separated systems in the Mocks Bottom/Swan Island and St. Johns areas to support industrial development.

Although the east side interceptor was operational by 1952, studies performed by the Oregon State Sanitary Service Authority (OSSA) in 1953 identified three outfalls upstream of Portland Harbor where bypass of sewage to the river occurred during dry weather periods (Stevens & Thompson 1964). For example, Stevens & Thompson (1964) estimated as much as 17 million gallons a day (dry weather flows) discharged from diversion structures south of the Sullivan Gulch Pumping Station upstream of Portland Harbor. After completion of the eastside and downtown interceptors, the City implemented a number of efforts to further reduce discharges to Portland Harbor, including the following (City of Portland 1966b):

- Expanding existing systems
- Adding pumping stations to pick up low areas below the interceptors
- Reconstructing or adjusting diversion structures (e.g., raising dams, adjusting orifice diameters, raising or lowing weirs)
- Rerouting combination sewers to discharge above rather than below diversions, thus eliminating dry weather (sanitary) flows from entering the river
- Where separated systems were constructed, requiring property owners to separate and reroute site sanitary and storm discharges to the appropriate system
- Requiring installation of pretreatment systems for industrial wastes
- Design of the Linnton-Guild's Lake sewerage system to provide facilities for diversion of dry weather flow for existing public sewers and to allow industry to connect to the City system, thus eliminating private industrial and sanitary outfalls to the river
- Design of a stormwater and sanitary system on Swan Island to replace the existing combined system.

In those areas where the City provided separate sanitary and stormwater systems, most properties rerouted their sanitary and stormwater discharges to the appropriate City conveyance. In 1967, the City established additional efforts to ensure compliance with the City's requirements for the separation of storm and sanitary wastes and connection to an approved sewer (City of Portland 1967a). These efforts included review of connection and plumbing records, field inspections, and dye testing to verify that property owners had appropriately rerouted their discharges within the City system. Only stormwater and uncontaminated cooling water could be discharged to the storm system, and only sanitary waste and approved industrial wastewater could be discharged to the sanitary sewer system. For example, in the fiscal year 1967–1968, 77 properties were investigated in Portland Harbor and 23 of these were required to reroute either their stormwater or wastewater (City of Portland 1969). By 1976, investigations and rerouting of wastewater from storm lines to the sanitary sewer were completed (City of Portland 1976).

In the 1960s, the City replaced an existing non-municipal system with a separated sanitary and storm system on Swan Island and Mocks Bottom. In 1969, the City constructed sanitary lines to the International Slip area. In 1972, the City also built a storm system in the St. Johns area to allow development to occur in a previously undeveloped area (depicted in as-built drawings on Portland Maps).

A 1964 study by Stevens & Thompson focused on the sewer systems in the Guild's Lake-Linnton area in northwest Portland and in the area served by the east side interceptor (Stevens & Thompson 1964). Eight combined sewage/stormwater collection systems were identified in the Guild's Lake-Linnton area on the west side of the Willamette River, all within the current study area of the Portland Harbor Superfund Site. Most of the collection systems were noted to drain areas dominated by industrial and commercial activities and discharge directly to the Willamette River. This area encompassed drainage to outfalls currently designated OF-17 through OF-24A. Stevens & Thompson also indicated that there were 12 private outfalls in this area discharging industrial wastes (several discharging only cooling water) directly to the Willamette (Stevens & Thompson 1964).

Stevens & Thompson estimated future volumes in the system to assess design parameters for the needed new diversion structures. The analysis compared the 1964 capacities for different interceptor lines/areas against population and flow projections for 1980. Stevens & Thompson determined that increased flows in the southeast and northwest sections, roughly comprising outfalls OF-11 through OF-17 (west side, in the study area) and OF-26 through OF-38 (east side, upstream of the study area), respectively, would exceed capacity of the interceptors during periods of maximum flow in the future. However, Stevens & Thompson determined that other sections of the system would be overloaded even if the volume of sewage allowed to bypass diversions in these outfalls were reduced (i.e., if more sewage was diverted to the treatment plant). Based on the results of this study, Stevens & Thompson recommended new and renovated facilities to alleviate overloading and meet the Sanitary Authority's capacity requirements (Stevens & Thompson 1964).

In 1968, the City initiated sewer projects to direct sanitary sewage discharges directly to the CBWTP, including industrial wastewater discharges that were discharging directly to the river in the Guild's Lake-Linnton area. The 1968 projects included construction of a pumping station, the Portsmouth Tunnel, which crossed under the river to the CBWTP, and the northwest interceptor. Construction was completed the following year for the tunnel, pump station, and a portion of the northwest interceptor (from Guild's Lake to the Railroad Bridge) (City of Portland 1969). By 1973, the northwest interceptor (from the Railroad Bridge to Linnton) had been completed.

In summary, all City outfalls served by the northwest interceptor were separated, except for the two small residential combined basins in Linnton. Much of this northwest area was not previously served by City outfalls but rather discharged industrial waste directly to the river or to Doane Lake. The interceptor provided a means for industries to eliminate discharges to water bodies by routing their wastewater to the interceptor, although some industries continued to discharge to the river, including some under permits from the State.

**1977–1990**

During this time period, the City conducted studies to determine design parameters for future CSO controls and continued implementing programs to detect illicit connections. The City also constructed additional stormwater systems to provide storm service for areas that were being redeveloped or to improve existing drainage. The City incorporated into the municipal system some existing storm and sanitary lines in the newly annexed Rivergate area.

In 1972, the City estimated that the amount of combined sewage overflowing to the Willamette River and Columbia Slough was over 10 billion gallons per year (City of Portland 2001b).

In 1977, the CRAG undertook a study of the greater Portland area to evaluate municipal and industrial wastewater and urban stormwater, including the quality of the overflows from the City of Portland CSO system (CRAG 1977). The study provided a baseline for reevaluating Portland's CSO system. (Several of the reports cited below state different numbers of outfalls in the combined system; this most likely is due to the combination of two outfalls into one or the elimination of some outfalls during the time these reports were completed.) At the time of the CRAG study, there were 43 CSO outfalls in the City's entire Willamette River CSO system (25 on the east side and 18 on the west side), each draining a basin. Of the 43 outfalls discharging to the Willamette River, 16 discharged within the study area, and 27 were upstream of the study area up to RM 17.2. The resulting report contained descriptions of each outfall drainage basin, including acreage served, land-use type, pipe size, interceptor, diversions, and details on specific diversions, where applicable. The report also distinguished, in acreage, the type of collection system for each drainage area/outfall. Table 3.2-4 summarizes that information (CRAG 1977).

The CRAG study calculated the average annual runoff of suspended solids, settleable solids, biological oxygen demand (BOD), ammonia, phosphorus, and bacteria from CSOs in the City's entire CSO system, based on historical rainfall data. The study area focused on municipal outfalls discharging to the Willamette River that were within the City of Portland's boundary, and provided discharge estimates for 1975 and projected land use and conditions for the year 2000. Table 3.2-5 lists the 1975 results for suspended solids from the lowest downstream location to the highest upstream location measured.

In 1986 the City issued a Sewer Outfall Report, the purpose of which was to gather information to design future pollution abatement programs (City of Portland 1986). In the 1986 report, the City stated that the CSO system included 57 CSO outfalls, with 44 of the CSOs discharging to the Willamette River (16 of which were in the Portland Harbor study area), and 13 discharging to the Columbia Slough (City of Portland 1986). An outfall inspections program was instituted to include observations of the outfalls during the dry season to identify the condition of the outfall and to determine if the dry weather flow had any sanitary component. Dry weather flows could include groundwater infiltration, permitted and non-permitted process water (such as cooling water discharges and landscape irrigation), or illicit connections of sanitary discharges downstream of diversions. These dry weather flows were, and continue to be, analyzed for bacteria to determine if there is any sanitary contribution, and flow volumes are estimated where dry weather flows were evident (City of Portland 1986).

**1990–Present**

Sanitary interceptor lines run south to north through the main trunk lines, paralleling the riverbanks. Interceptors are large lines that collect sanitary and combined flows and direct them to the treatment plant. Some combined lines have diverters that allow excess flow to discharge to the lower Willamette River during heavy storms for a portion of the rainfall event; this is called a CSO. The diverters are designed to protect the interceptor from excess stormwater inflow by diverting the peak portions of the flow. Combined systems without CSO diverters direct all sanitary and stormwater flow to the treatment plant.

In 1991 the City began to further reduce the CSO events to the Willamette from about 100 events per year to four events per year in winter and one event every three summers by 2011 (City of Portland 2001b).

In 1994, it was estimated that the CSO system discharged an average of 4.8 billion gallons of stormwater (~80 percent) and untreated sewage and pretreated industrial waste (~20 percent) to the river between RM 4 and 17 (CH2M Hill 1994). The discharges occurred through 42 outfalls to the Willamette River, some of which overflowed nearly every time it rained (150 days), while others only overflowed 30 days per year (City of Portland 2001b). The City estimated an average of 50 CSO events (encompassing up to a total of 112 days) per year in the entire CSO system (City of Portland 1998).

Around this same time, it was determined that dry weather discharges of untreated sewage (including pretreated industrial wastewater discharges) were also still occurring in some portions of the City system due to periodic failure of the system to function properly, vandalism, illicit discharges, blockages caused by a variety of sources, and groundwater infiltration, which resulted in the discharge of untreated sanitary sewage through CSO outfalls directly to the Willamette River. These dry weather discharges involved relatively small volumes and are different than wet weather CSO events, which occur when the combined sanitary sewage and stormwater flows exceed the system's capacity during rain events. The City completed improvements to the CSO system between 1992 and 1996, and signed a Stipulation and Final Order with DEQ in 1992 in which it agreed to eliminate the dry weather discharges by 1996 (DEQ 1996).

In 1994, the City prepared a CSO Management Plan with recommendations to address wet weather overflow discharges, including the following:

- Implementation of "Cornerstone Projects" focused on reducing the volume of stormwater to the system
- Implementation of storage and treatment facilities to eliminate the CSO discharges to the Columbia Slough as required in the Stipulation and Final Order
- Implementation of storage and treatment facilities along the Willamette River ("Big Pipe project") to control the CSO discharges as required by the Amended Stipulation and Final Order.

The City completed for the 20-year project in 2011 (City of Portland2012). As described in Table 3.2-3, the CSO abatement projects include one or more of the following for each outfall (City of Portland 2008b):

- Completely separating storm and sanitary to create stormwater-only outfalls with stormwater treatment prior to discharge, where possible
- Completely sealing and abandoning outfalls or diversions to prevent overflows
- Reducing stormwater flows to the CSO system to minimize flow through the system during a storm event, such that the system meets the Amended Stipulation and Final Order standard
- Increasing the storage capacity for the CSO system to reduce the frequency of overflows to meet the Amended Stipulation and Final Order standard.

The primary means for increasing the storage capacity was through construction of the West Side Tunnel (completed in 2006) and the East Side Tunnel (completed in 2011). The City also controlled 16 CSO outfalls by 2006 and all remaining CSO outfalls by 2011. The goal of the abatement projects was to meet the design standard to control CSO discharges to an average of four events in the winter (November 1 to April 30) and one event in three summers (May 1 to October 31; City of Portland 2005). Between 2006 and 2009, there were a total of five events for all Willamette River outfalls that were controlled by 2006—fewer than an average of two events per winter since completion of construction of the West Side tunnel. The overflow points in the study area were outfalls OF-11 and OF-47.

The abatement projects, including the West Side Tunnel and the final selected design for the East Side Tunnel, are projected to meet the current CSO system demands and design standard through the year 2025. This projection is based on the assumption that other City programs will continue to implement mitigation measures to reduce stormwater flow to the overall CSO system by initiating additional projects (e.g., infiltration basins, green roofs, and other such stormwater reduction measures). The City has noted that additional efforts would be required to control CSO demands beyond 2025 (City of Portland 2005). The configuration and dates of the abatement project for the separate and combined sewer systems is shown on Figure 3.2-4.

The location and status of CSO outfalls, including a summary of abatements completed within the study area, is provided in Table 3.2-3 and shown in Maps 3.2-22a–m.

Table 3.2-3 also identifies whether stormwater from fully separated CSOs (i.e., where sanitary wastewater is sent to the CBWTP and stormwater is discharged to the lower Willamette River) was diverted to a different outfall or still utilizes the former CSO outfall; whether a partially separated CSO system conveys the combined sanitary and industrial wastewater and significantly reduced stormwater to the CBWTP except during extreme wet weather events when a portion of the combined flow overflows to the Willamette River due to capacity limitations; and shows the combined or CSO outfalls that were abandoned before the City's 20-year abatement program was initiated.

#### *Non-Municipal Conveyance Systems*

As described in Section 3.2.2, most historical industrial development occurred along the shoreline. At least through the 1960s, very few shoreline facilities were connected to the municipal systems; nearly all managed their own stormwater and wastewater. Most of these discharges were combined (i.e., included stormwater and sanitary and/or industrial wastewater) (OSSA 1950; DOI 1967; Stevens & Thompson 1964). Figure 3.2-6 shows the areas not served by the interceptors in 1963; these areas were predominantly shoreline properties (OSSA 1963). Many of the non-municipal conveyance systems served a single property, but there were several larger shared conveyance systems noted in historical reports such as the Oregon Terminals (currently International Slip) (OSSA 1963) and Swan Island (CH2M Hill 1957).

The Rivergate area was undeveloped until about the 1960s. Separate sanitary and storm systems were installed by the Port of Portland to provide conveyance services to this developing area. The Rivergate area was annexed into the City of Portland beginning in 1979 and was completed in 1989, and some of these conveyance systems were transferred to the City after annexation.

The OSSA conducted several surveys of industrial dischargers in Portland Harbor (OSSA 1963, 1966), and beginning in 1967, required waste permit applications to be submitted by dischargers (OSSA 1967a). Additional information about the State discharge permits is provided in Section 4.3.1.4.

#### *National Pollutant Discharge Elimination System Permits*

The Clean Water Act (CWA) prohibits any entity from discharging "pollutants" through a "point source" into a "water of the United States" unless they have an NPDES permit. The permit contains limits on what can be discharged, monitoring and reporting requirements, and other provisions to ensure that the discharge does not hurt water quality or people's health. In essence, the permit translates general requirements of the CWA into specific provisions tailored to the operations of each permittee discharging pollutants.

The NPDES Stormwater Program, which commenced in 1992, regulates stormwater discharges from three potential sources: municipal separate storm sewer systems (MS4s), construction activities, and industrial activities. Most stormwater discharges are considered point sources, and operators of these sources may be required to receive an NPDES permit before they can discharge. The State of Oregon is authorized by USEPA Region 10 to implement the NPDES Stormwater Program and administer its own stormwater permitting programs.

Current discharges to the lower Willamette River within the study area are regulated by a variety of NPDES permits, including multiple general NPDES stormwater permits (e.g., 1200-Z, 1200-C); the City of Portland, Port of Portland, and Multnomah County MS4 NPDES discharge permits; the City of Portland NPDES wastewater discharge permit (primarily for the discharge from the CBWTP to the Columbia River, but also including CSOs and sewer system overflows into the lower Willamette River); individual stormwater NPDES permits; and individual wastewater NPDES discharge permits. ODOT also has its own MS4 NPDES discharge permit for runoff from state highways. These permits are described further in Section 4.4.1.4. Many stormwater discharges are not regulated through MS4 or NPDES permits.

#### 3.2.3.1.12 Federal Navigational Channel

Congress authorized the lower Willamette River as a federal navigation project through the Rivers and Harbors Act in June 1878. Its purpose was to deepen and maintain parts of the Columbia and Willamette rivers to a 20-ft minimum depth. The USACE maintains the channel for both rivers, both of which have been deepened at various intervals since that time. Most significantly, the authorizations affecting the lower Willamette River depth occurred as follows: –25 ft CRD in 1899, –30 ft CRD in 1912, –35 ft CRD between 1930 and 1935, and, finally, –40 ft CRD in 1962.

The current project authorization, as modified by Congress in 1962, encompasses 11.7 miles of the Willamette River in Portland and 103.5 miles of the Columbia River below Vancouver, Washington. Work on the authorized –40-ft-deep CRD channel from Portland and Vancouver to the Pacific was completed in 1976. The Willamette River channel from the Broadway Bridge (RM 11.7) to the mouth (RM 0) varies in width from 600 to 1,900 ft, with an average width of approximately 1,700 ft.

In 1999, Congress authorized the Willamette River (and Columbia River) deepening to –43 ft CRD. The existing 600-ft-wide, 40-ft-deep Willamette River navigation project channel would be deepened from RM 0 to RM 11.6 (USACE 1999c).

#### 3.2.3.1.13 Dredging and Capping Activities

This section presents Portland Harbor dredging and capping activities since 1997. This date corresponds to the oldest data used in the presentation and evaluation of analytical data in this report. This section also notes ongoing and upcoming dredging projects in Portland Harbor.

In certain areas of Portland Harbor, periodic dredging is necessary to maintain the authorized depth of the navigation channel, as well as to maintain operational depths at docks and wharfs. Major changes in the river's bathymetry from 1888 to 2001 are depicted on Map 3.1-13. This map shows how the original shoreline was altered and filled, where material was excavated to create new uplands, and how most of the original channel has been deepened by at least 10 to 20 ft to reach the authorized federal navigation channel depth of –40 ft CRD. Historically, periodic dredging was needed to maintain this depth in two major shoaling areas, between RM 8 and 10, particularly in the western half of the channel, and from RM 2 to 2.5 in the eastern portion of the channel. The navigation channel has not been dredged since January 1997, although dredging at various docking facilities has occurred on an as-needed basis (Map 3.2-23).

Currently, maintenance dredging has been suspended until issues are resolved regarding dredging within the boundaries of the Portland Harbor Superfund Site. The lack of maintenance dredging over the past 10 years has resulted in significant shoaling of the channel. Many areas of the channel are now less than 40 ft deep, which is a significant navigation hazard to large cargo ships that require a minimum draft of 40 ft. A critical area of shoaling in the river that needs immediate attention is Post Office Bar at RM 2. According to the USACE (2010a), this dredging was proposed for completion in the summer of 2011.

Dredging projects undertaken since 1997 by the Port of Portland, USACE, the City of Portland, and private parties are listed in Table 3.2-6. This table is an update of a similar compilation provided in the Programmatic Work Plan (Integral, Windward, Kennedy/Jenks, Anchor, and GSI 2004) and the Round 2 Report. The dredging projects that are italicized in the table indicate recent projects for which a USACE public notice has been issued, but specific information about dredging dates and amounts was not available in time for this report. Note that the issuance of a permit does not mean that the project was implemented or that the volume of dredged material indicated in the table was dredged. Furthermore, the table does not distinguish between single events and multi-year permits. Map 3.2-23 shows the locations of dredging and capping operations between RM 1 and 11.8, since the most recent USACE-sponsored dredging of the federal navigation channel in January 1997.

Since 1997, the Port of Portland has performed maintenance dredging at its marine Terminals 2, 4, and 5 (Table 3.2-6). Maintenance dredging has also been performed by Schnitzer Steel Industries, Inc. (Schnitzer berths in International Terminal Slip, RM 4), Chevron (Willbridge Terminal, RM 7.5), the City of Portland (Portland Fire Bureau Station 6 Dock, RM 9.7), the former Goldendale Aluminum Company (Goldendale

Aluminum facility dock, RM 10), and CLD Pacific Grain (Irving Elevator Terminal, RM 11.4). The City of Portland project also included cap placement, as noted below. Brief descriptions of these dredging projects are provided below:

- Schnitzer performed maintenance dredging of its berths located inside the International Terminal Slip in 2004 under two separate permits. Approximately 77,000 $yd^3$ of material was dredged from Berths 1, 2, and 3 under Permit #199100099. Maximum target dredge depths were –42, –38, or –24 ft CRD, depending on the location within the slip. Outside the slip, Schnitzer dredged approximately 61,000 $yd^3$ of material from Berths 4 (to –42 ft CRD) and 5 (to –36 ft CRD) under Permit #199200812. The permits for both projects allow for biannual maintenance dredging through January 31, 2009 (USACE 2004a,b).
- In 2001, Chevron Products removed approximately 15,000 $yd^3$ of material from both sides of its pier at Willbridge Terminal. The dredging was performed under a maintenance dredging permit issued in 1997. Sediments were removed to a target dredge depth of –40 ft CRD (PNG 2001).
- The former Goldendale Aluminum Company conducted maintenance dredging at its dock in 2000. Dredging volumes were not provided, but material was removed to –38 ft CRD (CH2M Hill 2000).
- The City of Portland performed maintenance dredging of the Portland Fire Bureau Station 6 Dock in 2005. The area approaching the dock was dredged to –12 ft CRD, and the area adjacent to the dock was dredged to –10 ft CRD. Altogether, 4,130 $yd^3$ of dredged material was removed. In accordance with the permit, both areas were capped to bring the bottom grade to between –10 and –11 ft CRD. Approximately 1,190 $yd^3$ of capping material was used (CH2M Hill 2005).
- CLD Pacific Grain performed maintenance dredging at two separate locations at the Irving Elevator Terminal in 2009. The dredge volume was approximately 1,430 $yd^3$ (NRC 2009). In 2001, approximately 5,000 $yd^3$ was removed to a permitted depth of –40 ft CRD (Harding ESE 2001).
- The dock area offshore of Glacier NW (RM 11.3E) was dredged in 2004, but no as-built drawings are available to determine the volume removed and the exact footprint.
- As part of the Terminal 4 Early Action removal, approximately 13,000 $yd^3$ of contaminated sediments were dredged from Slip 3 in 2008 (discussed further below).

As of 2011, maintenance dredging was planned for the dock areas offshore of Gunderson, the Portland Shipyard (Cascade General), and at ConocoPhillips and Chevron properties in the Willbridge Terminal complex.

Dredging and/or capping have also been completed or are in process as part of remedial actions at selected Portland Harbor locations. Interim removal action activities at Terminal 4 are underway and are scheduled to occur in two phases. The first phase, which was completed in the fall of 2009, included dredging of approximately 13,000 $yd^3$ of contaminated sediment and placement in an offsite disposal facility, isolating contaminated sediment in the head of Slip 3 with a cap made of an organoclay-sand mix, and re-contouring the slope of the bank along Wheeler Bay and planting native vegetation to minimize erosion and improve stability. The second phase of the Terminal 4 project includes a combination of dredging, capping, and monitored natural recovery (MNR) in areas not completely addressed by the first phase, as well as construction of a confined disposal facility in Slip 1. The second phase design and implementation of the Terminal 4 removal action will be implemented after the Portland Harbor Record of Decision (Port of Portland 2011b).

At the ARCO BP terminal, a new steel sheetpile wall was installed in 2007 to stabilize the facility and prevent migration of contaminants to the river. The following year, the concrete revetment riverward of the new sheetpile wall was removed, along with 13,293 $yd^3$ of underlying and nearshore contaminated sediment, which was disposed of offsite. Clean fill was placed in the excavated area (DEQ 2010b).

Two in-river sediment capping projects (McCormick and Baxter and Gasco) have taken place since 2003. McCormick and Baxter was a remedial action project following a CERCLA Record of Decision, and Gasco was an interim removal action. Both projects are described below.

Sediment cap construction activities at McCormick and Baxter, a former wood treating facility, were completed in September 2005. (Subsequent modifications to the cap were performed in October 2005 and July 2007.) The cap's shoreward boundary extends from the south end of the property north into Willamette Cove (RM 6.8). Its offshore boundary extends up to approximately 700 ft from the shoreline. In Willamette Cove, the cap extends offshore up to approximately 600 ft. Approximately 23 acres of contaminated sediments were capped with 2 ft of sand. More highly contaminated areas were capped with 5 ft of sand. In addition, multiple areas of the cap overlying seeps were constructed with a total of 600 tons of organoclay, a bentonite or hectorite clay altered to be hydrophobic. The cap design incorporated different types of armoring (i.e., articulating concrete block mats and rock) in the nearshore areas to reduce erosion (DEQ 2005).

In 2005, pursuant to a USEPA Administrative Order, approximately 15,300 $yd^3$ of tar and tar-contaminated sediment were removed by dredging from the riverbank and nearshore area adjacent to the Gasco facility and disposed of at the Chemical Waste Management landfill in Arlington, Oregon. After the removal action, an organoclay mat was placed along an upper-elevation band of the shoreline dredge-cut. This mat was secured with placement of cap sand and quarry spalls over the clay mat. The remainder of the removal area (0.4 acres) received 1 ft of cap sand and 0.5 ft of erosion protection gravel. In addition, 2.3 acres of the area surrounding the removal area received 0.5 ft of “fringe cap” sand material. The removal action also created a depression into which potential seepage could be captured and localized for future response. Construction activities took place between August and October 2005 (Parametrix 2006).

#### 3.2.3.2 Cultural Resources

The Portland Basin historically offered access to abundant natural resources in the rivers and on land, and many of these resources are still present. The following discussion will focus on some of the resources known to be of historic and contemporary cultural significance to Native peoples.

Fish are among the resources most frequently utilized by Tribes in the Portland Basin. Culturally significant species include salmonids, lamprey (eels), eulachon (smelt), and sturgeon. Native peoples also fished for a variety of other resident species, including mountain whitefish (*Prosopium williamsoni*), chiselmouth (*Acrocheilus alutaceus*), northern pikeminnow (*Ptychocheilus oregonensis*), peamouth (*Mylocheilus caurinus*), and suckers (*Catostomus* spp.) (Butler 2004; Saleeby 1983).

In addition to fish, the river provided harbor seals (*Phoca vitulina*) and sea lions (*Eumetopias jubatus* [Steller sea lion] and *Zalophus californianus* [California sea lion]). These marine mammals were historically found on the Columbia River as far upstream as The Dalles and in the lower Willamette River to Willamette Falls. These migratory marine mammals followed the migrations of eulachon, the winter and spring salmon runs, and the lamprey runs up the rivers. Although difficult to hunt, they were a favored resource, especially sea lions.

Rivers, sloughs, and wetlands also provided habitat for a great variety of waterfowl. The Portland Basin lies on the Pacific Flyway and supports large populations of both migrating and resident ducks, geese, and swans. Modern waterfowl populations in the lower Columbia-Portland Basin area number between 200,000 and 250,000 during the winter. The most abundant species today are Canada geese (*Branta canadensis*), mallards (*Anas platyrhynchos*), northern pintails (*Anas acuta*), and American wigeons (*Anas americana*). Winter populations begin gathering in October and peak in December, and then decline into late winter and early spring. Resident populations consist primarily of Canada geese, mallards, and wood ducks (*Aix sponsa*) (Oregon Wetlands Joint Venture 1994:4–5; Tabor 1976:2A:294–295, 310–311).

Of land mammals historically found in the Portland Basin, deer and elk were the most frequently utilized by Native people. In addition to their meat, deer and elk hides were widely used for clothing, and deer and elk bones and antlers were transformed into a wide variety of tools, weapons, and ornamental objects. There are two species of deer native to this area, the more common black-tailed deer (*Odocoileus hemionus*) and Columbian white-tailed deer (*O. virginianus leucurus*). The latter is a subspecies found only in the lower Columbia River drainage. Both species would have lived on the floodplain, but the Columbia white-tailed deer was especially well-adapted to brushy riparian areas. Elk (wapiti, *Cervus elaphus*) were also common on the floodplain, especially in the winter, but, like black-tailed deer, preferred grasslands and prairies rather than the brushier woodlands that extended across much of the river bottoms.

Other animals that were hunted primarily for their furs and hides (and which could have been found in the Portland Basin) included black bear, mountain lion, bobcat, wolf, raccoon, fox, beaver, river otter, weasel, muskrat, mink, gray squirrel, wood rat, and mountain beaver (Franchère 1967:110; Gough 1992:664; Merk 1968:97; Moulton 1990:208, 327, 329, 344–345, 351, 434–435, 439; Ross 1986:104 [1849]; Spaulding 1953:41). These were used chiefly in making blankets, robes, and other articles of clothing.

Of equal importance in both subsistence and trade were a variety of plants. The best known of these was wapato (*Sagittaria latifolia*), the tubers of which were a major food source. Wapato grows in marshes and shallow ponds and lakes on the floodplains of the lower Columbia and Willamette valleys (as well as in some scattered wetlands in the interior valleys), but it was nowhere as abundant in this region as in the Portland Basin. The other plant-food staple was camas bulbs (*Camassia quamash*). This plant grew profusely in the wet prairies of the lower Columbia and in the interior valleys of western Oregon and Washington, although the historical abundance of camas on the Columbia and Willamette river floodplains is uncertain.

Other native plants were and continue to be gathered for food and medical purposes as well. These include a variety of roots, bulbs, nuts, and berries. Herbaceous plants, root bark, and sticks of woody stemmed plants are also gathered as raw material for making items like fishing nets, cordage, baskets, mats, and woven hats.

Historical and contemporary uses of these resources overlap, and access to suitable patches continues to be both a challenge and an essential element of maintaining local Tribal cultural knowledge, practices, and traditions. It is important to note that locations that are and were used for hunting, fishing, and gathering, are likely locations for archeological sites containing important cultural artifacts. There may be multiple strata of artifacts at some locations reflecting different eras of site usage.

#### 3.2.3.3 Recreational

The lower Willamette River provides many natural areas and recreational opportunities, both within the river itself and along the riverbanks. According to the Oregon State Administrative Rules, OAR 340-041-0340, Table 340A, the designated beneficial use of the lower Willamette River includes hunting, fishing, boating, and water contact recreation. Adults and children use the lower Willamette River for boating, water skiing, swimming, and other water activities. Recreational fishing is conducted throughout the lower Willamette River basin and within the study area, both by boaters and from locations along the banks.

Within the study area, Cathedral Park, located under the St. Johns Bridge, includes a sandy beach area and a public boat ramp and is used for water skiing, occasional swimming, and waterfront recreation. Recreational beach use also may occur within Willamette Cove, which is a riverfront natural area; in Swan Island Lagoon; and on the southern end of Sauvie Island, which is within the study area. Swan Island Lagoon includes a public boat ramp. Additional recreational beach areas exist on the northern end of Sauvie Island and in Kelley Point Park, both of which are downstream of the study area. Willamette Cove is currently used by transients and recreational beach users that approach the area by uplands access or by boat, but is planned to be turned into an open greenspace that will serve as an extension of the Willamette River Greenway. Potential human use beach areas in the study area are shown in Map 3.2-24.

#### 3.2.3.4 Transients

Transients have been observed along the lower Willamette River, including some locations within the study area. The observation of tents and makeshift dwellings during RI sampling events confirms that transients were present along some riverbank areas. Transients are expected to intermittently utilize this area in the future. Transients may be using the lower Willamette River as a source of drinking water. Conversations were conducted with transients about their consumption of fish or shellfish from the Willamette River as part of a project by the Linnton Community Center (Wagner 2004, pers. comm.). The transients that were contacted reported harvesting and consuming various fish species as well as crayfish and clams. It should be noted that the most common clam species in the Portland Harbor is an invasive species, the harvesting of which is illegal. Many of the individuals indicated that they were in the area temporarily, move from location to location frequently, or have variable diets based on what is easily available. However, the interviews did not quantify the frequency or duration of transient presence along the shoreline.

#### 3.2.3.5 Diving

Diving activity also occurs in the lower Willamette River. In the study area, the majority of divers are expected to be commercial divers. Some diving for scientific purposes, including some aspects of site characterization for this RI, has occurred in the study area. Diving is done by several groups of people, including the public for recreation and gathering of biota for consumption; the sheriff's office for investigations and emergency activities; and, commercial divers for a variety of purposes, including marine construction, underwater inspections, routine operation and maintenance, and activities related to environmental work.

#### 3.2.3.6 Commercial Fishery

The Oregon State Administrative Rules, OAR 340-041-0340, Table 340A, includes fishing as a designated beneficial use of the lower Willamette River. The exact extent to which commercial fishing occurs within the study area is currently not known. No reports of commercial fisheries for anadromous salmonids on the Willamette River have been found. A commercial crayfish fishery exists in the lower Willamette River. Crayfish landings must be reported to ODFW by water body and county. Per ODFW, the crayfish fishery is not considered a large fishery (Grooms 2008, pers. comm.). Based on ODFW's data for 2005–2007, no commercial crayfish landings were reported for the Willamette River in Multnomah County.

#### 3.2.3.7 Drinking Water

Under Oregon State Administrative Rules, OAR 340-041-0340, Table 340A, the designated beneficial use of the lower Willamette River includes private and public domestic water supply after adequate pretreatment to meet drinking water standards. There are no known current or anticipated future uses of the lower Willamette River within Portland Harbor as a private or public domestic water supply. According to the City of Portland, the primary public domestic water source for the City of Portland is the Bull Run watershed, which is supplemented by a groundwater supply from the Columbia South Shore Well Field (City of Portland 2008a). In addition, the Willamette River was determined by the Portland City Council not to be a viable water source for future City of Portland water demands through 2030 (City of Portland 2008a); further action by the Council would be needed before any exploration of this source could begin (City of Portland 2010). Upstream of Portland Harbor, the City of Wilsonville uses the Willamette River as a domestic water source following treatment, and the City of Sherwood will be using the Willamette River beginning in 2013.

#### 3.2.3.8 Residential

Residential areas in the vicinity of the study area include the neighborhood districts of Linnton, Northwest, Pearl, Old Town, Overlook, University Park, Cathedral Park, Eliot, and Lloyd. Several of these communities have been established for decades, although the Pearl District is a recent name for a former warehouse and industrial area just north of downtown where many of the warehouses have been converted into lofts, and new multistory condominiums have also been developed on previously vacant land. Most of the residential areas in the study area are not located in the riparian zone adjacent to the river, with the exception of homes on Sauvie Island and some condominiums in the Pearl District.

#### 3.2.3.9 Restoration

There have not been any restoration projects within the Portland Harbor study area, although there has been some planning for a restoration project at Alder Point at the former Alder Creek Lumber site on the southern tip of Sauvie Island. Despite the area's urbanization, the combination of existing stream channel and open space provide greater opportunity for watershed rehabilitation on the Willamette's west side than on the east side.